BWRF Wastewater Study and Utility Plan

WASTEWATER UTILITY PLAN

DRAFT | August 2023

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Contents

Chapter 2 – Facility Assessment

Chapter 3 – Liquids Stream Evaluation

Appendices

Tables

Figures

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Abbreviations

AACE International	Association for the Advancement of Cost Engineering International
ADA	average daily annual
ADAF	average daily annual flow
ADMM	average daily maximum month
ADMMF	average daily maximum month flow
AGS	aerobic granular sludge
As	Arsenic
aSRT	aerobic solids retention time
AWPF	advanced water purification facility
B	Boron
BAF	biologically activated filter
Be	Beryllium
BNR	biological nutrient removal
BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
Broomfield	City and County of Broomfield
Btu	British thermal units
BWRF	Broomfield Wastewater Reclamation Facility
C	Celsius
Carollo	Carollo Engineers
CBAT	carbon-based advanced treatment
Cd	Cadmium
CDPHE	Colorado Department of Public Health and Environment
CDPS	Colorado Discharge Permit System
cf	cubic foot
cfm	cubic feet per minute
CFU	colony forming units
CH_4	methane
CIP	capital improvement plan
cm	centimeter
CMAR	Construction Management at Risk
CMU	concrete masonry unit
CN	Cyanide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COD	chemical oxygen demand
Cu	Copper
D3	cellulosic biofuel
D5	advanced biofuel
DAF	dissolved air flotation
DAFT	dissolved air flotation thickener

DB	Design-Build
DBB	Design-Bid-Build
DIP	ductile iron pipe
DM	daily maximum
DMX	deammonification
DO	dissolved oxygen
DPR	direct potable reuse
EBPR	enhanced biological phosphorus removal
EI&C	electrical, instrumentation, and controls
EPA	Environmental Protection Agency
EQ	equalization
eRIN	Electric Renewable Identification Number
F	Fahrenheit
FRP	fiber-reinforced plastic
ft/sec	feet per second
GAC	granular activated carbon
GBT	gravity belt thickener
GHG	greenhouse gas
gpcd	gallons per capita per day
gpd/sf	gallons per day per square foot
gpm	gallons per minute
GWP	Global Warming Potentials
GWR	Great Western Reservoir
HA	health advisory
HFPO-DA	hexafluoropropylene oxide dimer acid
Hg	Mercury
HI	Hazard Index
hp	horsepower
H_2S	hydrogen sulfide
HRT	hydraulic retention time
HVAC	heating, ventilation, and air conditioning
I-25	Interstate 25
I&C	instrumentation and controls
IFAS	integrated fixed film activated sludge
Incentive Program	Voluntary Incentive Program
IPCC	Intergovernmental Panel on Climate Change
IPR	indirect potable reuse
IPS	Influent Pumping Station
IQR	interquartile range
IR	internal recycle
IRA	Inflation Reduction Act
ITC	investment tax credit
IWC	instream waste concentration

IX	ion exchange
kW	kilowatt
kWh	kilowatt-hour
lb	pound
lb VSS/cfd	pounds of volatile suspended solids per cubic feet per day
LCFS	Low Carbon Fuel Standard
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
MBR	membrane bioreactor
MCC	motor control center
MCL	maximum contaminant level
MCWB	mean coincident wet bulb
MG	million gallons
mgd	million gallons per day
mg/L	milligrams per liter
mJ/cm^2	millijoules per square centimeter
mL	milliliter
mL/gram	milliliter per gram
MLR	mixed liquor recycle
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
mm	millimeter
MMBtu	million British thermal units
Mn	Manganese
Mo	Molybdenum
MOB	(NUVODA) Mobile Organic Biofilm
MOP 8	*Design of Water Resource Recovery Facilities Manual of Practice No. 8*
mt	metric ton
MWAT	maximum weekly average temperature
MWh	megawatt-hour
NCWCD	Northern Colorado Water Conservancy District
NFPA	National Fire Protection Association
NFRWQPA	North Front Range Water Quality Planning Association
ng/L	nanograms per liter
NH_4	ammonia
nm	nanometer
N_2O	nitrous oxide
NOEC	no observed effect concentration
NPDES	National Pollutant Discharge Elimination System
NPV	net present value
OEM	original equipment manufacturer
O&M	operation and maintenance
OP	orthophosphorus

P3	Public-Private Partnership
Pb	Lead
PC	primary clarifier
pCi/L	picocuries per liter
PDR	Process Design Report
PFBS	perfluorobutanesulfonic acid
PFNA	perfluorononanoic acid
PEL	Preliminary Effluent Limitations
PFAS	per- and polyfluoroalkyl substances
PFOA	perfluorooctanoic acid
PFOS	perfluorooctanesulfonic acid
PHF	peak hour flow
PLC	programmable logic controller
POTW	Publicly Owned Treatment Works
ppcd	pounds per capita per day
ppd	pounds per day
pph	pounds per hour
pph/sf	pounds per hour per square foot
psig	pounds per square inch gauge
PSPS	Primary Sludge Pumping Station
PV	photovoltaic
PVC	polyvinyl chloride
RAS	return activated sludge
RDT	rotary drum thickener
REC	Renewable Energy Certificates
RFS	Renewable Fuel Standard
RIN	Renewable Identification Number
RNG	renewable natural gas
RO	reverse osmosis
RPS	Renewable Portfolio Standards
rTOC	recalcitrant TOC
RWTF	recycled water treatment facility
SC	secondary clarifier
SCADA	supervisory control and data acquisition
scf	standard cubic foot
scfm	standard cubic feet per minute
Se	Selenium
sf	square foot
sf/cf	square feet per cubic foot
SLR	solids loading rate
SoCalGas	Southern California Gas Company
SOR	surface overflow rate
SPA	state point analysis

SRT	solids retention time
SU	Standard Unit
SVI	sludge volume index
SWD	side water depth
TDS	total dissolved solids
TENORM	Technologically Enhanced Naturally Occurring Radioactive Materials
TIN	total inorganic nitrogen
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TOC	total organic carbon
TOrC	trace organic contaminants
TP	total phosphorus
TPAD	temperature-phase anaerobic digestion
TS	total solids
TSS	total suspended solids
TWAS	thickened waste activated sludge
UF	ultrafiltration
UFAT	unified fermentation and thickening
Utility Plan	Wastewater Utility Plan
UV	ultraviolet
UV/AOP	ultraviolet advanced oxidation processes
VFA	volatile fatty acids
VFD	variable frequency drive
VOC	volatile organic compounds
VS	volatile solids
VSR	volatile solids reduction
VSS	volatile suspended solids
WAS	waste activated sludge
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WET	whole effluent toxicity
WPC-DR-1	State of Colorado Design Criteria for Domestic Wastewater Treatment Works
WQBEL	water quality-based effluent limit
WQCC	Water Quality Control Commission
WQCD	Water Quality Control Division
WRF	wastewater reclamation facility
WRI/WBCSD	World Resources Institute and the World Business Council for Sustainable Development
WTF	water treatment facility
Xcel	Xcel Energy
yd^3/d	cubic yards per day

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EXECUTIVE SUMMARY

The City and County of Broomfield (Broomfield) operates the Broomfield Wastewater Reclamation Facility (BWRF), which provides wastewater treatment and resource recovery for the Broomfield service area. This Wastewater Utility Plan (also referred to as a Master Plan) summarizes the current and future needs of the BWRF and defines a $524 million capital improvement program (CIP) to address these needs. The following sections briefly introduce and summarize the content of this Wastewater Utility Plan. The Master Plan is also required to document projects and allow for State approval.

Planning Objectives

As defined by Broomfield staff, the primary objectives of the Wastewater Utility Plan are to:

- Define future regulations and develop a phased strategy for implementing solutions.
- Provide treatment capacity to accommodate population growth through 2050.
- Mitigate operational challenges related to reliability and redundancy of existing assets.
- Maintain a high level of public standing through aesthetics and minimization of odors.
- Develop a cost-effective plan for implementation.

Secondary objectives include sustainability and energy efficiency.

Planning Requirements

The basis of planning for the WRF includes review of historical process performance and operational strategies, projecting future flows and loads based on anticipated growth, defining upcoming liquid and solids stream regulatory and capacity requirements, benchmarking greenhouse gas (GHG) emissions, and documenting current asset condition with recommendations for rehabilitation or replacement.

Flows and Loads

The WRF is rated for an average daily maximum flow and organic treatment capacity of 12 million gallons per day (mgd) and 23,018 pounds per day (ppd) as 5-day biochemical oxygen demand (BOD_5). Like many Front Range facilities, the BWRF has experienced decreasing per capital hydraulic loading due to water conservation in the service area, while per capita loading has remained relatively stable. Consequently, hydraulic capacity expansion is likely required by 2031 while load capacity expansion may be required as early as 2027 based on Broomfield's population projections. Table ES.1 summarizes rated, current, and projected capacity through 2050, based on a 2050 population of 127,800 (Broomfield's June 2023 projection).

Table ES.1 Summary of Treatment Capacity

Constituent	Current Rated Capacity	Current Operating Maximum Month	Percent of Current Capacity	2050 Projected Capacity Needs
Flow (mgd)	12	8.15	68%	14
BOD_5 (ppd)	23,018	17,266	75%	30,250

Regulations

Broomfield is on track to earn full credit under CDPHE's Voluntary Incentive Program, delaying Regulation 31 limits by 10 years.

Current and future regulatory requirements are typically a major driver of capital improvements for wastewater treatment facilities. A number of anticipated regulatory drivers that will have significant ramifications on future BWRF improvements include increasingly stringent nutrient removal requirements under Regulation 31, effluent temperature reduction, and emerging contaminants such as per- and polyfluoroalkyl substances (PFAS).

Greenhouse Gas Emissions

Wastewater reclamation facilities are often the single largest municipal user of electricity, due to energy needed for aeration and pumping. As such, documenting and tracking GHG emissions is desirable due to the large impact on overall BWRF emissions. A 2021 baseline GHG emission calculation was developed in parallel with projections for 2028, summarized in Table ES.2. Improvements planned such as beneficial reuse of biogas will reduce GHG emissions by a projected 7 percent per unit of wastewater treated, despite more stringent limits and increased chemical demands.

Table ES.2 GHG Emissions Summary and Projections

Period	Annual GHG Emissions (mt of CO_2e/year)	Unit GHG Emissions (mt of CO_2e/year/MG)
2021 Baseline	7,052	3.0
2028 After Improvements	9,178	2.8

Notes:
CO_2e carbon dioxide equivalent
MG million gallons
mt metric ton

Asset Condition

The BWRF is generally in good condition and consistently complies with current permit requirements. However, the solids digestion and flow equalization processes are aging and require improvements to achieve Broomfield's planning objectives. The liquid stream process is also capacity limited. Because the site is constrained, a sequence of steps to update is required for these updates. Figure ES.1 identifies key asset improvements recommended in the CIP.

Facility Assessment Site Plan

1 PRIMARY TREATMENT
- Replace flow equalization basin and pumping, and primary sludge pumping.
- Evaluate primary clarifier concrete and mechanism condition to consider future steps.

2 PRELIMINARY TREATMENT
- Upgrade HVAC and odor control air flows.
- Plan rebuild of influent pumps.
- Consider influent flow measurement improvements, address metals corrosion in girt room, and evaluate hydraulic capacity and limitations in channels for peak flow.

3 SITE ELECTRICAL
- Recommend a full plant one-line diagram.
- Update arc-flash study and provide equipment labeling.
- Replace switchboard in West Generator Building.
- Replace site lighting.

4 SECONDARY TREATMENT
- Replace South Train capacity with new treatment train.
- Replace Middle Train IR, RAS, and WAS pumps and associated electrical, and IFAS system.
- Replace old North Train blowers
- Replace secondary clarifier mechanisms for SC 3 and 4.

5 I&C SYSTEMS
- Improve aeration/DO control.
- Plan PLC and instrumentation upgrades in parallel with project work.

6 SOLIDS THICKENING
- DAF redundancy for WAS thickening.

7 ODOR CONTROL
- Conduct odor control study.
- Construct new odor control system at new EQ facility and combine nearby existing foul air flows.
- Replace odor control fans, associated ductwork, and metal building.

8 DIGESTION
- Construct new digestion complex, including digesters, dewatering feed pumps, and pre-dewatering sludge storage.
- Consider capacity and desire to achieve Class B biosolids and beneficial reuse of biogas.

9 TERTIARY TREATMENT
- Replace filter backwash pumps and HVAC in chemical rooms.
- Evaluate UV disinfection hydraulics and update, if necessary.
- Consider logical approach to reuse filtration system expansion.
- Add jockey reuse pump in fourth bay and upgrade reuse pump VFDs.

10 DEWATERING
- Replace conveyors.
- Increase centrate storage/consider treatment.
- Replace centrifuges with larger capacity units or 3 centrifuges if mechanical connections and access can be defined.
- Plan for sludge storage volume and replace dewatering feed pumps.

Figure ES.1 BWRF Facility Asset Condition Site Plan

Alternatives Analysis

Considering these planning requirements, the Master Plan evaluated alternatives for liquid stream treatment, solids handling, satellite treatment, and potable reuse feasibility. Key considerations of these evaluations include the following.

Liquids Stream	• Address upcoming capacity demands and regulatory requirements. • Update/expand existing treatment process within constrained site.
Solids Handling	• Overhaul solids handling & digestion to increase resource recovery. • Beneficially reuse biogas and provide biosolids reuse options.
Satellite Treatment	• Balance capacity needs at BWRF with regional growth. • Cost and challenges appears to outweigh benefits at this time.
Potable Reuse	• Understand considerations for future water supply resiliency. • Begin coordination efforts across City departments and facilities.

Capital Improvements Plan

A 5-phase CIP for improvements at the BWRF was developed based on the timing of project needs, sequencing of projects, and maximizing usage of the existing site, as shown in Figure ES.2.

Figure ES.2 BWRF CIP – Proposed Improvements in 5 Phases

CIP Schedule and Costs

The proposed CIP construction schedule, key considerations, and planning level cost estimates are shown in Table ES.3. Key drivers in the costs are capacity, asset renewal, biosolids, reuse, and regulatory requirements. Table ES.4 allocates the costs amongst these drivers. The sequence of design, permitting, construction, and commissioning of the work over the next 10 years is shown in Figure ES.3.

Table ES.3 Proposed CIP Schedule and Costs

Project Phase	Construction Schedule	Key Considerations	Project Cost Estimate
1	2024-2025	Site Preparation for Solids	$36,843,000
2	2026-2028	Capacity Drivers, Performance, Resource Recovery	$176,368,000
3	2029-2030	Timing of Load Growth, Asset Upgrades, Reuse Approach, Timing of PFAS Limits	$118,656,000
4	2031-2032	Timing of Flow Growth, Treatment Approach, Temperature Limits	$63,514,000
5	2037-2038	Timing of Regulation 31 Limits and Approach to Treatment/Reuse	$128,111,000

Table ES.4 CIP Costs by Project Driver

Project Driver	Total Cost	Percent of Total Cost
Capacity	$87,167,500	17%
Asset Renewal	$104,055,350	20%
Biosolids	$92,750,850	18%
Reuse	$33,348,300	6%
Regulatory	$206,170,000	39%
Total	**$523,492,000**	

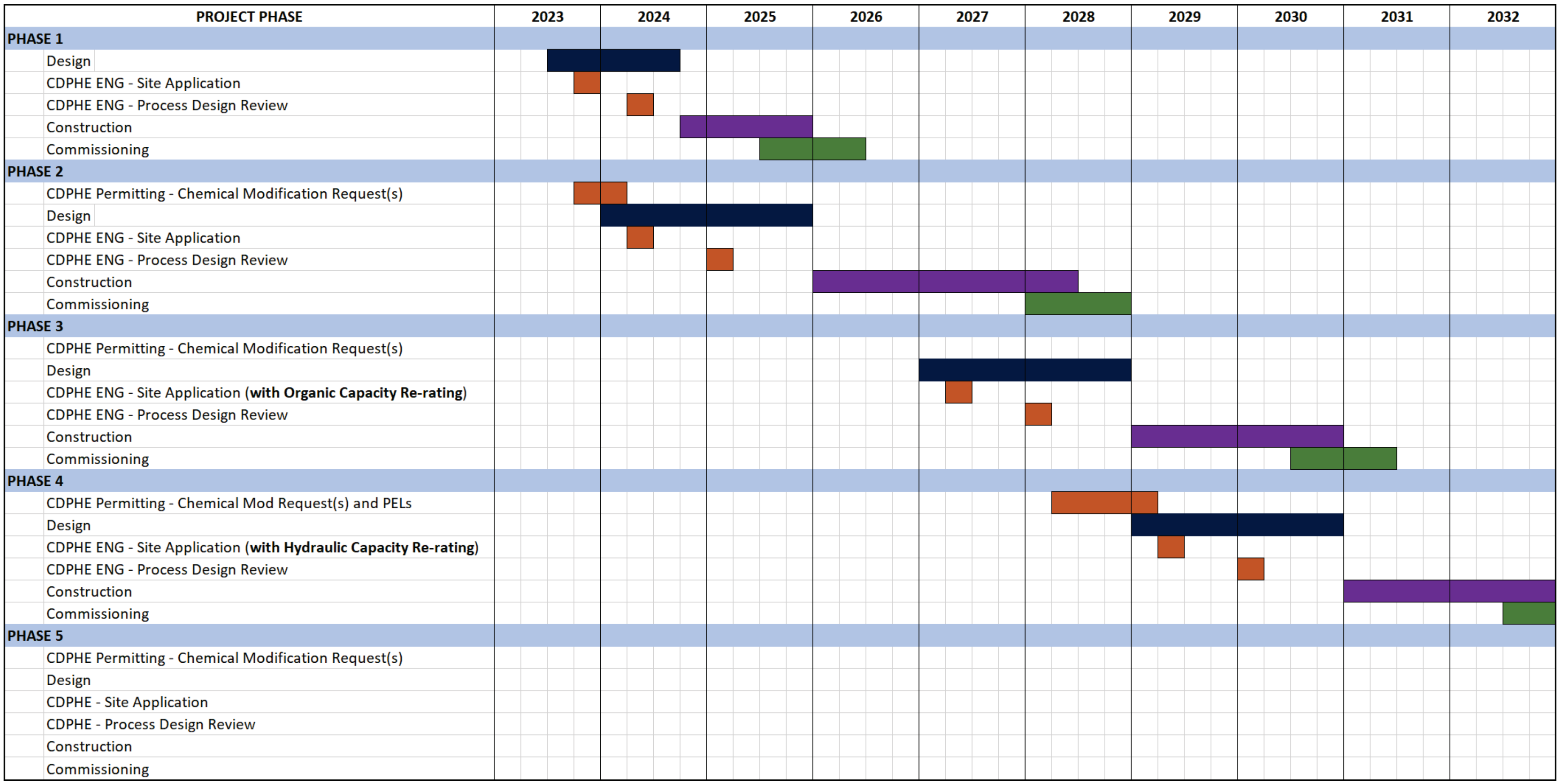

Figure ES.3 BWRF CIP – Schedule Over Next 10 Years

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Chapter 1

BASIS OF PLANNING

This chapter reviews the basis of planning for the City and County of Broomfield's (Broomfield) Wastewater Reclamation Facility (BWRF). This includes current flows and loads, projected flows and loads, regulatory drivers, and a summary of current greenhouse gas (GHG) emissions.

1.1 Wastewater Utility Planning Overview

The BWRF last completed a Wastewater Utility Plan in 2011. Sometimes referred to as a Master Plan, a Wastewater Utility Plan summarizes the current and future needs of the wastewater conveyance and treatment infrastructure system. Carollo Engineers (Carollo) has been retained by Broomfield to update the Wastewater Utility Plan specifically related to the BWRF. Wastewater conveyance infrastructure is being evaluated separately.

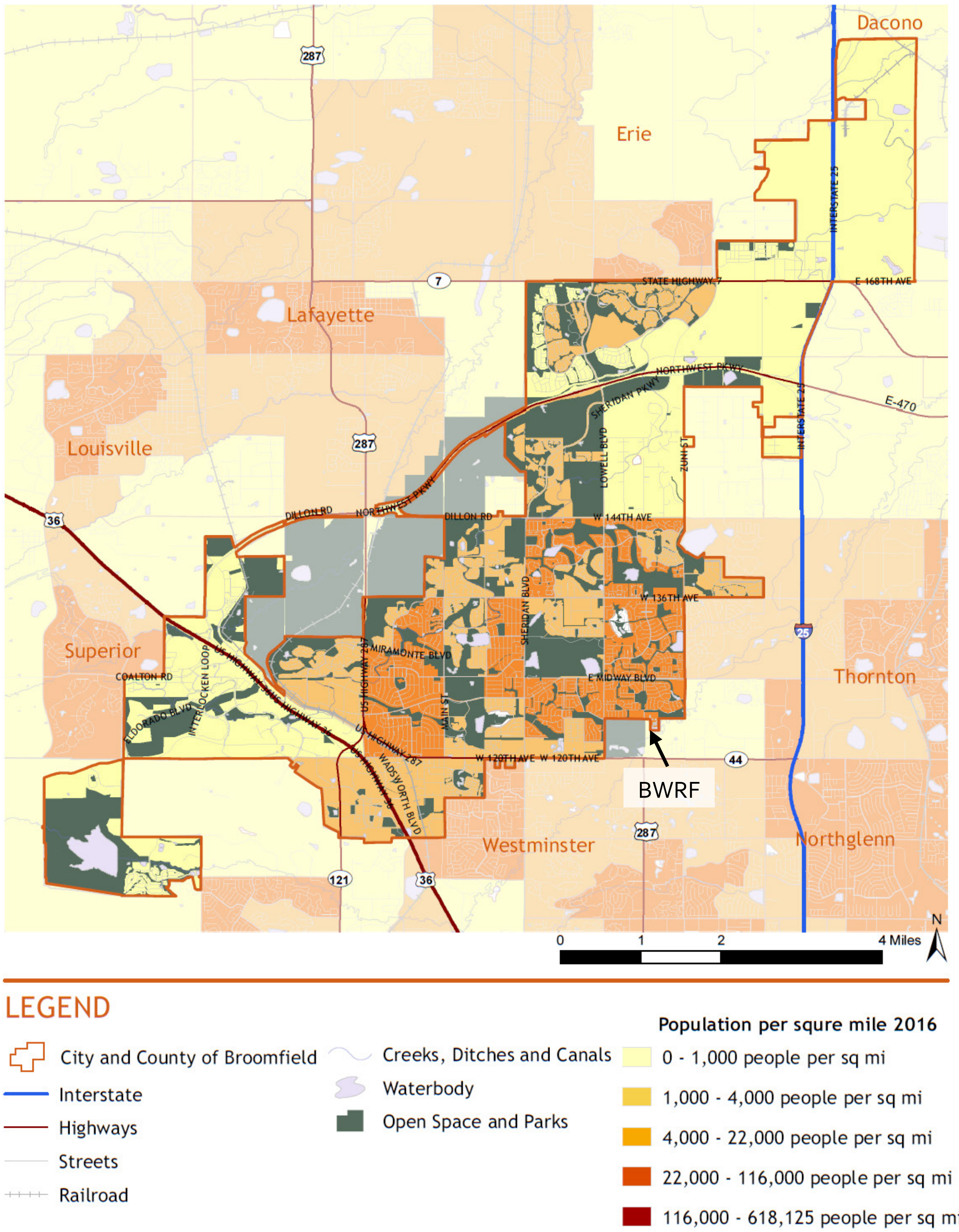
In Colorado, the Colorado Department of Public Health and Environment (CDPHE) is the approval authority for the location and design of wastewater treatment facilities. Prior to approving modifications to existing facilities, CDPHE requires that the modifications align with an approved Wastewater Utility Plan. Prior to 2010, the Denver Regional Council of Governments provided local agency review and approval of regional water quality plans, but no longer serves in that role. The North Front Range Water Quality Planning Association (NFRWQPA) has since taken on local oversite of Broomfield.

This Wastewater Utility Plan for the BWRF reviews the capacity, regulatory, and asset needs of the facility and develops a plan for the implementation of capital improvements. Upon approval by the Broomfield City Council, it will be submitted to NFRWQPA for approval and will then allow approval by CDPHE of subsequent facility improvements.

1.2 Flow and Loads

1.2.1 Service Area Overview

The BWRF service area is assumed to remain relatively unchanged through the year 2050, the planning target considered in this Wastewater Utility Plan (Utility Plan). The service area is shown in Figure 1.1.



Source: City and County of Broomfield Comprehensive Plan Update, November 1, 2016

Figure 1.1 BWRF Service Area

1.2.2 Historical Wastewater Flows and Loads

Five years of historical data was provided by Broomfield (2017 to 2022) to determine which set of existing data is most representative of recent trends to use as the basis of projections. Historical influent data and trends are provided in this section.

Daily influent flows from January 2017 to August 2022 are shown in Figure 1.2. The peak observed in Spring 2021 is likely reflective of a wet spring in combination with relatively dry weather from 2017 to 2020.

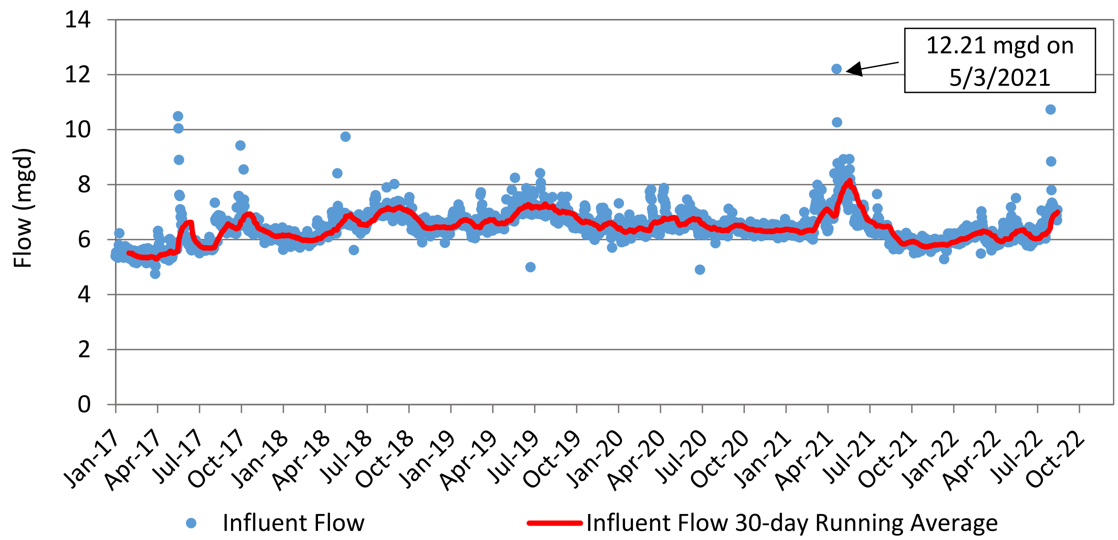


Figure 1.2 Daily Influent Flow and 30-day Running Average from 2017-2022

Daily influent 5-day biochemical oxygen demand (BOD_5) loads from January 2017 to August 2022 are shown in Figure 1.3. The large peak observed in 2017 is assumed to be due to a failure event of BWRF's dissolved air flotation (DAF) thickening system in which excess waste flows were diverted to the plant influent and upstream of the autosampler.

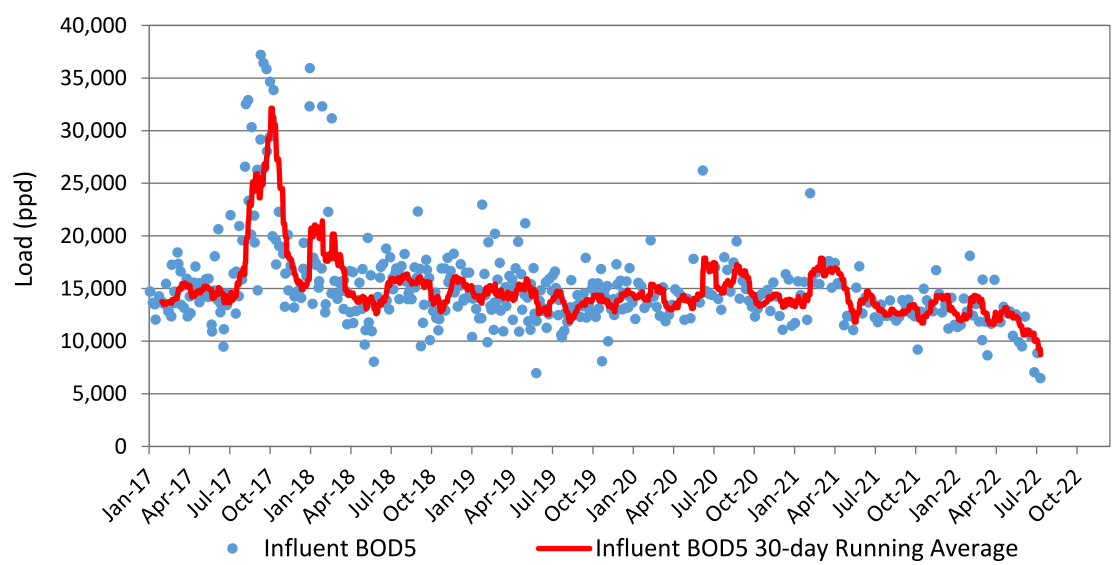


Figure 1.3 Daily Influent BOD_5 Load and 30-day Running Average from 2017-2022

Daily influent total suspended solids (TSS) loading from January 2017 to August 2022 are shown in Figure 1.4. Similar to BOD_5, the large peak observed in 2017 is assumed to be due to a failure event of the BWRF's DAF thickening system in which excess waste flows were diverted to the plant influent and upstream of the autosampler. It is important to note that a portion of the influent TSS load into the plant is due to discharge of drinking water residuals to the collection system. This is discussed in detail as part of subsequent chapters.

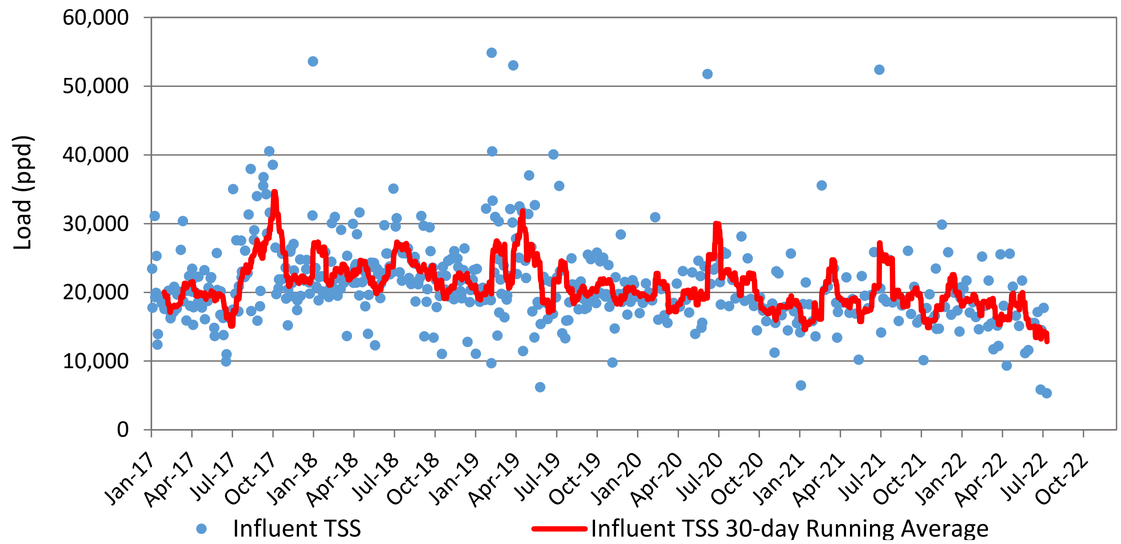


Figure 1.4 Daily Influent TSS Load and 30-day Running Average from 2017-2022

Daily influent total Kjeldahl nitrogen (TKN) and ammonia (NH_4) loads from January 2017 to August 2022 are shown in Figure 1.5. A stepwise increase in daily TKN load was observed in early August 2017, which was maintained until a stepwise decrease was observed around December 2019 that returned loads back to early 2017 levels. The average daily TKN load between January 2017 and August 2017 was about 2,400 pounds per day (ppd). This average daily load increased to about 2,900 ppd between August 2017 and December 2019, and then returned to about 2,400 ppd between January 2020 and August 2022. The 2017 stepwise increase occurred abruptly between two consecutive sampling dates (August 2, 2017, was 2,446 ppd and August 8, 2017, was 3,072 ppd), which may be indicative of a change in sampling technique. The stepwise decrease between 2019 and 2020 occurred over numerous sampling dates during the end of 2019 and the beginning of 2020. NH_4 is typically 60 to 70 percent of the TKN measurement; therefore, TKN and NH_4 datasets tend to mirror each other. However, this 2018 to 2020 plateau of higher daily TKN loads was not observed in the NH_4 loading.

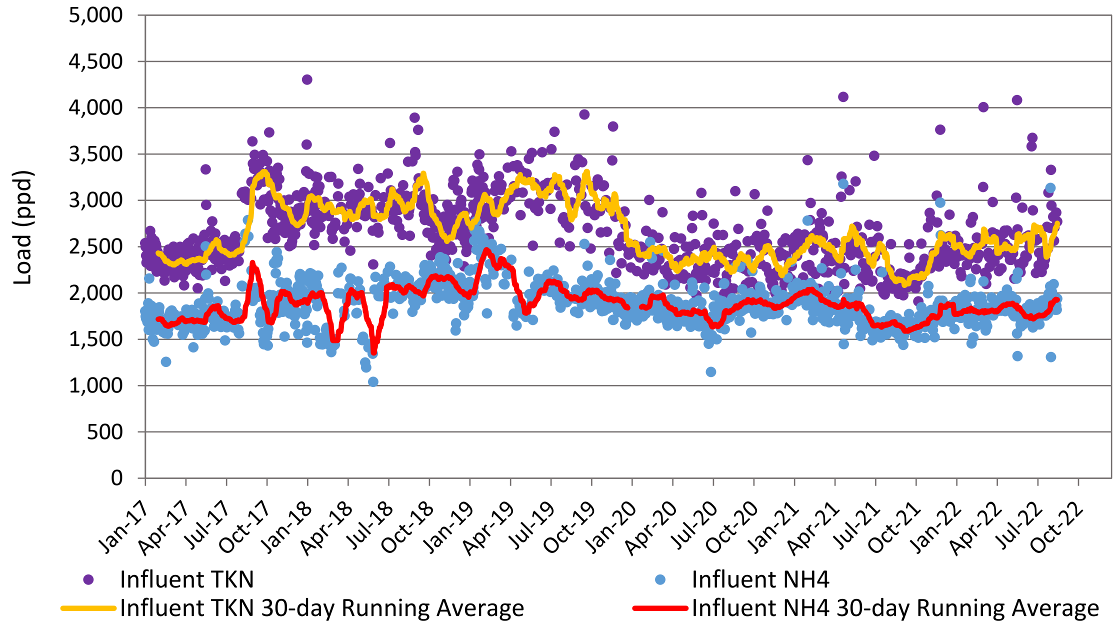


Figure 1.5 Daily Influent TKN and NH_4 Loads and 30-day Running Averages from 2017-2022

Daily influent total phosphorus (TP) loads from 2017 to August 2022 are shown in Figure 1.6. The large 2017 peak is also assumed to also be related to the DAF failure event. While not shown, the influent orthophosphorus (OP) load into the facility is lower than typical municipal wastewater (OP to TP ratio of much less than 0.5). This is largely attributed to the discharge of drinking water residuals into the collection system (which includes alum sludge) plus the addition of ferric chloride in the raw influent for odor control, which bind soluble phosphorus. This is discussed in detail in later chapters.

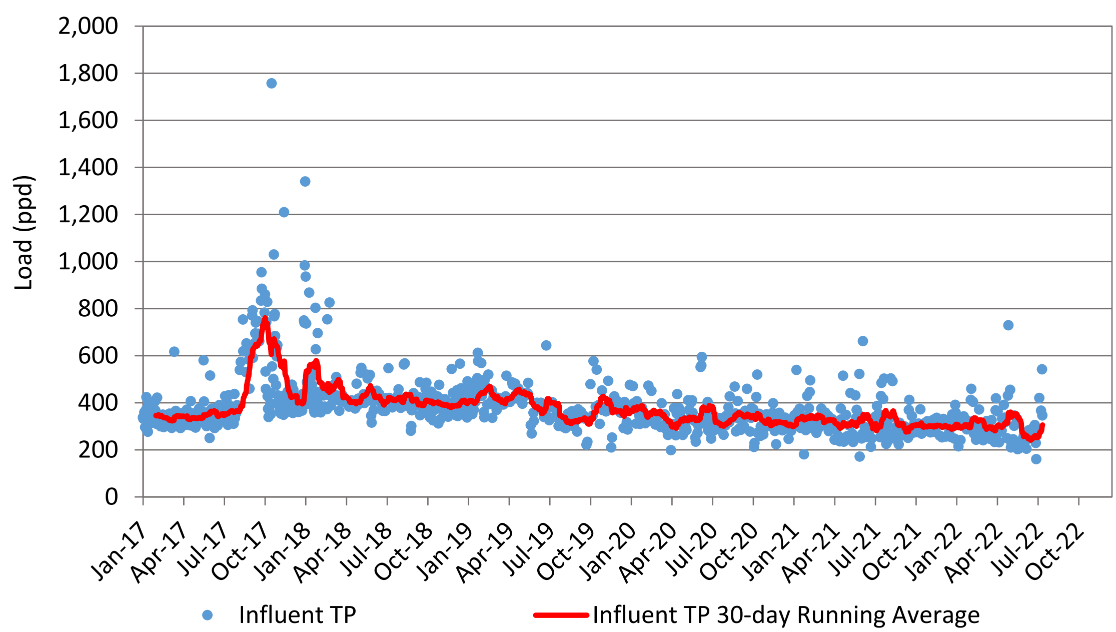


Figure 1.6 Daily Influent TP Load and 30-day Running Average from 2017-2022

1.2.2.1 Removal of Statistical Outliers

Loading projections are based on recent historical data that are representative of typical operating conditions. The datasets provided in Figures 1.2 through 1.6 are unedited and include all data points documented, including data that appear to be outliers. Outliers have the potential to skew data and misrepresent typical operating conditions. For example, unusual events such as the 2017 DAF failure. For a robust and appropriate analysis, Carollo recommends removing these outliers using a statistical method. Although this is not always necessary, in this case, it is believed to be warranted.

To avoid skewing the data, outliers were removed using the interquartile range (IQR) outlier exclusion method. The IQR is defined as the spread of values between a dataset's 25th percentile value (Q1) and 75th percentile value (Q3). In the IQR outlier exclusion method, lower and upper limits are set at Q1 minus 150 percent of the IQR and Q3 plus 150 percent of the IQR. If a data point falls outside those limits, it is labelled an outlier and excluded from the dataset. The IQR and Q1 and Q3-based limits were defined for the daily influent concentration dataset of each constituent of interest – BOD_5, TSS, TKN, NH_4, and TP – and outliers were excluded as shown in Figures 1.7 through 1.11. The removal of the outlier points associated with the 2017 BOD and TP peaks corresponding with the DAF failure is shown in Figures 1.7 and 1.11.

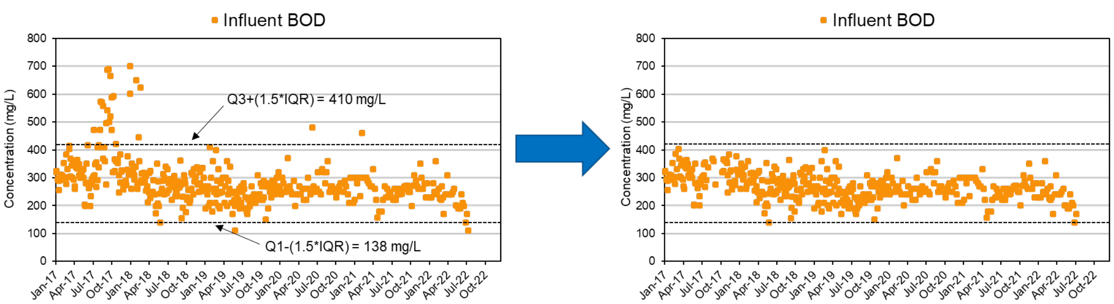


Figure 1.7 IQR Outlier Exclusion Method Applied to Daily Influent BOD Values

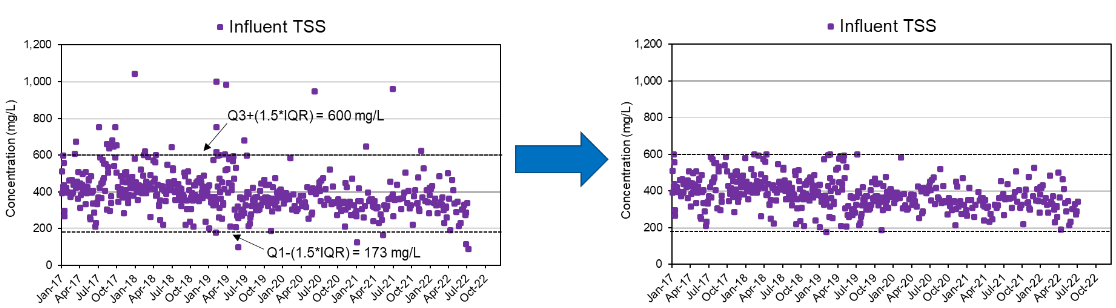


Figure 1.8 IQR Outlier Exclusion Method Applied to Daily Influent TSS Values

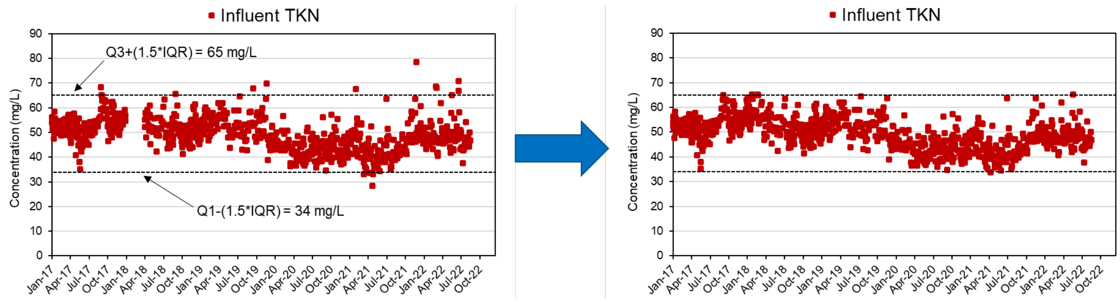


Figure 1.9 IQR Outlier Exclusion Method Applied to Daily Influent TKN Values

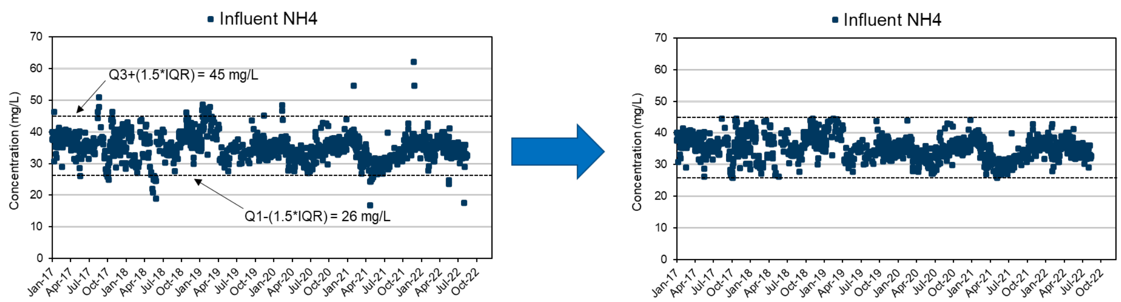


Figure 1.10 IQR Outlier Exclusion Method Applied to Daily Influent NH_4 Values

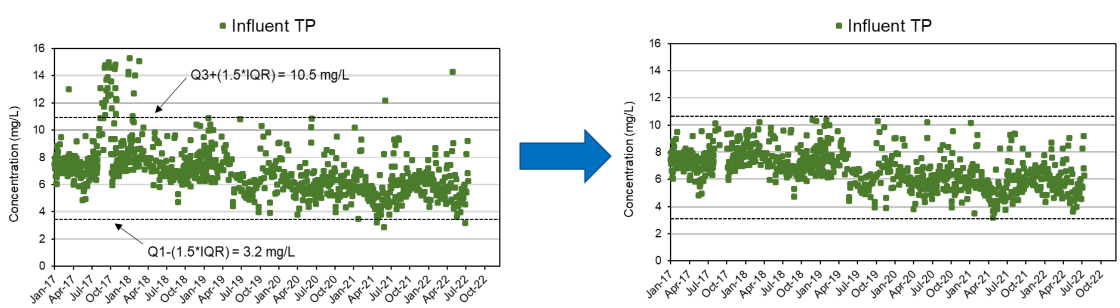


Figure 1.11 IQR Outlier Exclusion Method Applied to Daily Influent TP Values

1.2.3 Historical Flow and Load Trends

Annual average values were determined and plotted for each year (2017 to 2022) for each parameter of interest to clarify recent trends in the historical dataset and aid appropriate basis of projection selections. Per capita average daily annual (ADA) and average daily maximum month (ADMM) values also serve as the actual basis of projection values. ADA and ADMM values were established for planning purposes and to facilitate the process capacity analysis under current and future permit limits. The annual ADMM condition is represented by the annual peaks in the 30-day running average line plotted in Figures 1.2 through 1.6.

The 2017 to 2022 influent flow ADA and ADMM values are plotted in Figure 1.12 along with Broomfield's actual population provided by the Broomfield Planning Division. While Broomfield's population has steadily increased between 2017 and 2022 (from 69,658 to 78,202) with an approximate 2.3 percent annual growth rate, flow into the BWRF has remained relatively stable over the last 5 years (noting the high 2021 ADMM value corresponds to the spring 2021 peak highlighted in Figure 1.2). The 2017 to 2022 influent flow per capita ADA and ADMM values are plotted in Figure 1.13. A slight decreasing trend is observed in the per capita flows, dropping from an ADA and ADMM of 86 gallons per capita per day (gpcd) and 100 gpcd, respectively, to 80 gpcd and 90 gpcd in 2022. A full year of data is not available for 2022; however, when the 2022 values are removed, the decreasing trend is not apparent. Without a clear pattern, and in discussion with Broomfield staff, a continuation of the current per capita flows is assumed. If the next few years show a continual decrease in flows, a conservation factor could be applied to planning flows when the trend becomes apparent and consistent.

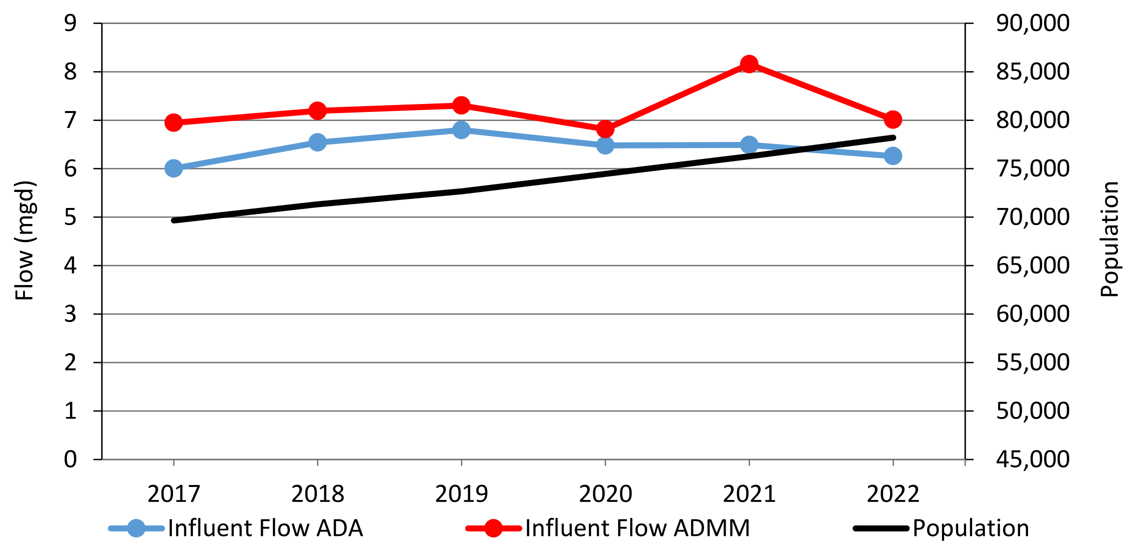


Figure 1.12 Influent Flow ADA and ADMM Values from 2017-2022

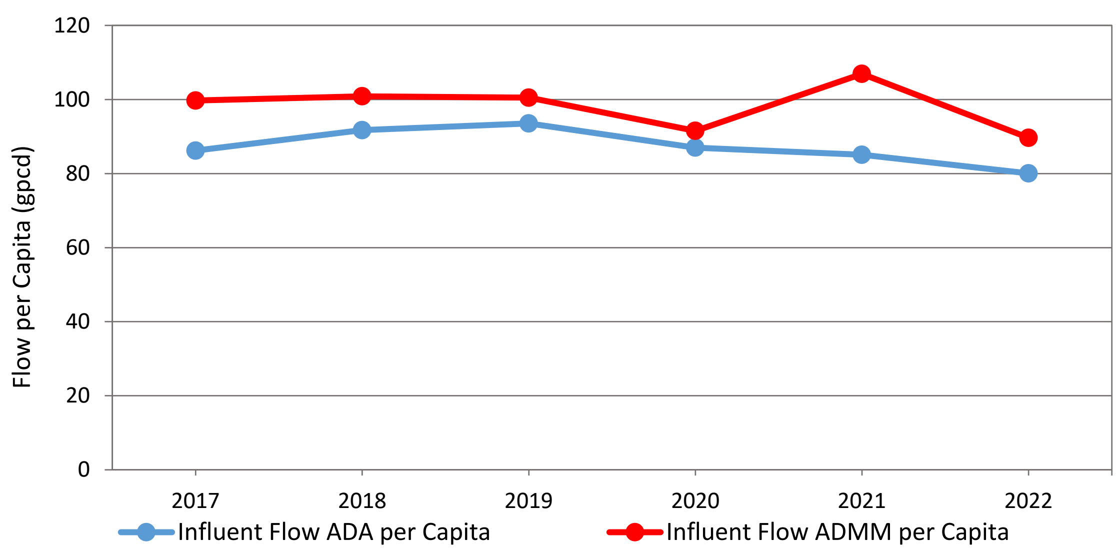


Figure 1.13 Influent Flow per Capita ADA and ADMM Values from 2017-2022

The 2017 to 2022 influent BOD_5 load ADA and ADMM values are plotted in Figure 1.14 with Broomfield's population. Influent BOD_5 loads show a decrease in trend over the last 5 years despite population growth. Aligned with these observations, the influent BOD_5 load per capita ADA and ADMM values plotted in Figure 1.15 also show a decreasing trend. The indicated relatively stable influent flows and decreasing BOD_5 loads have created a decreasing trend in influent BOD_5 concentrations as shown in Figure 1.16.

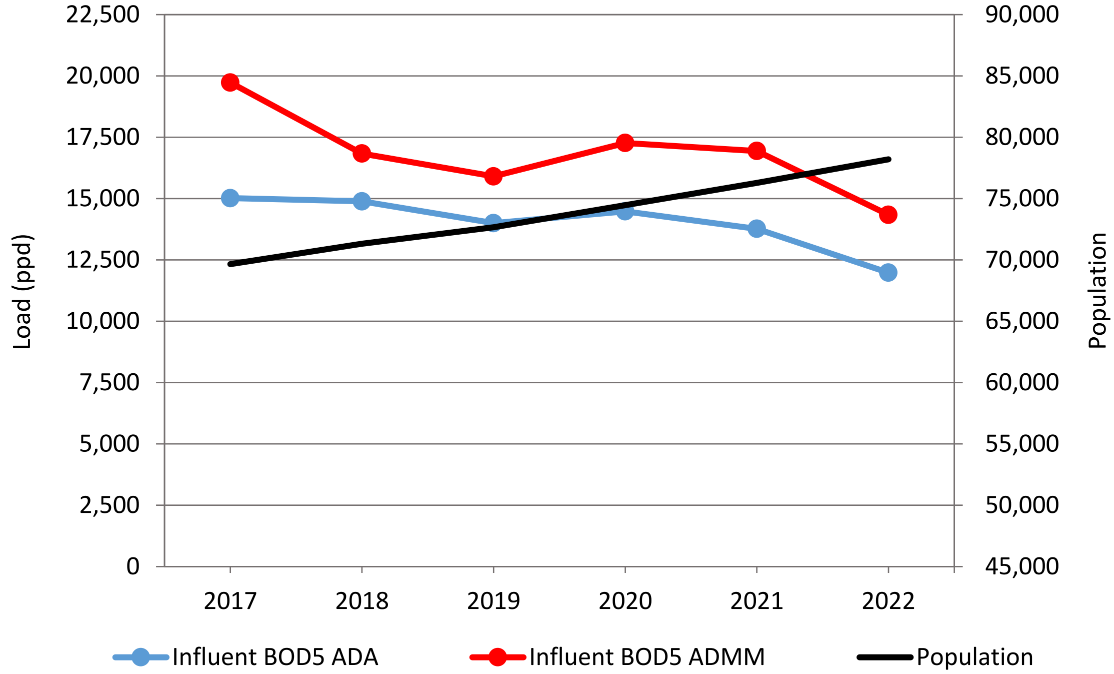


Figure 1.14 Influent BOD_5 Load ADA and ADMM Values from 2017-2022

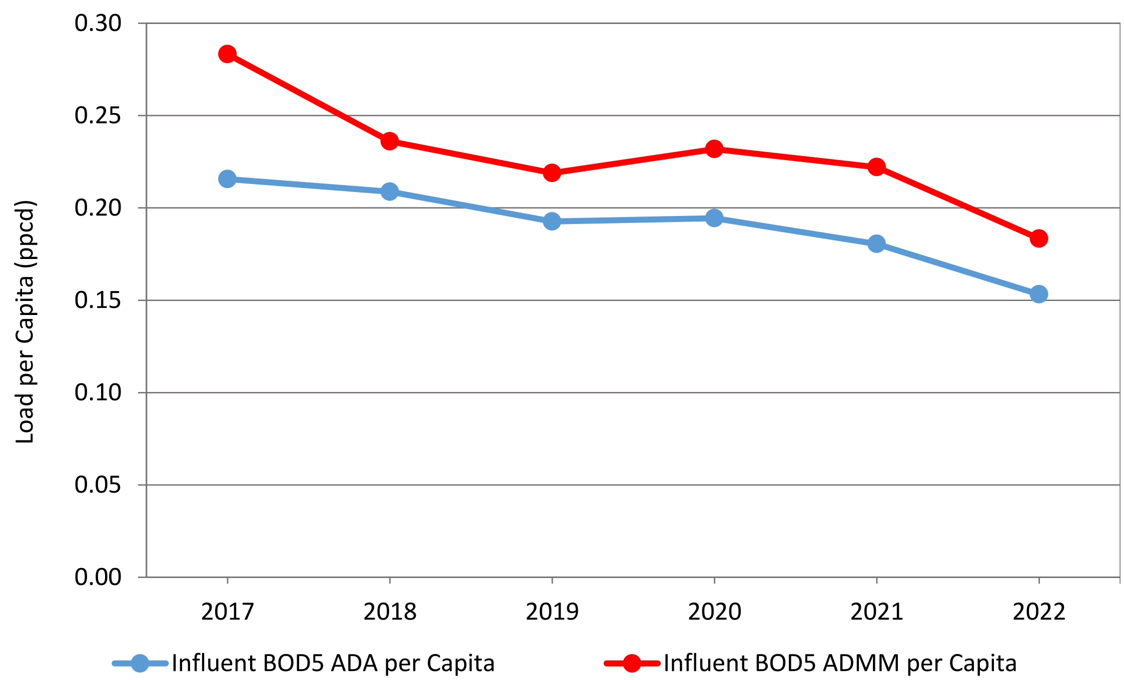


Figure 1.15 Influent BOD_5 Load per Capita ADA and ADMM Values from 2017-2022

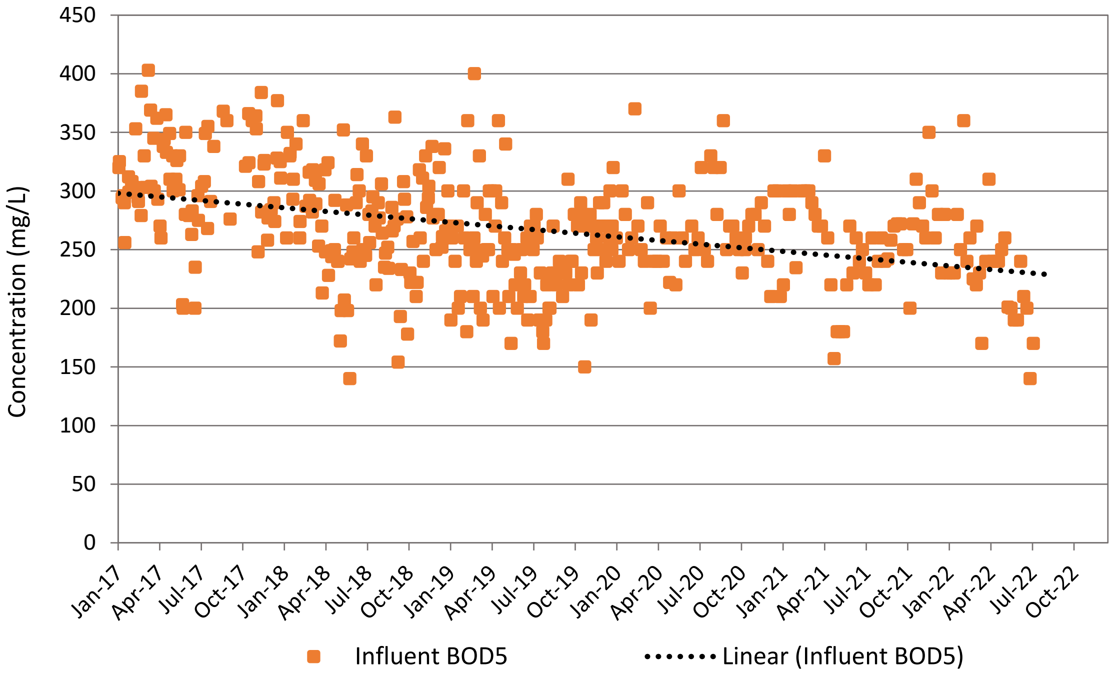


Figure 1.16 Daily Influent BOD_5 Concentrations from 2017-2022

The 2017 to 2022 influent TSS load ADA and ADMM and per capita ADA and ADMM values are displayed in Figures 1.17 and 1.18, respectively. As with BOD_5, a decreasing trend is observed in both plots which contributes to the decreasing trend in concentration as shown in Figure 1.19.

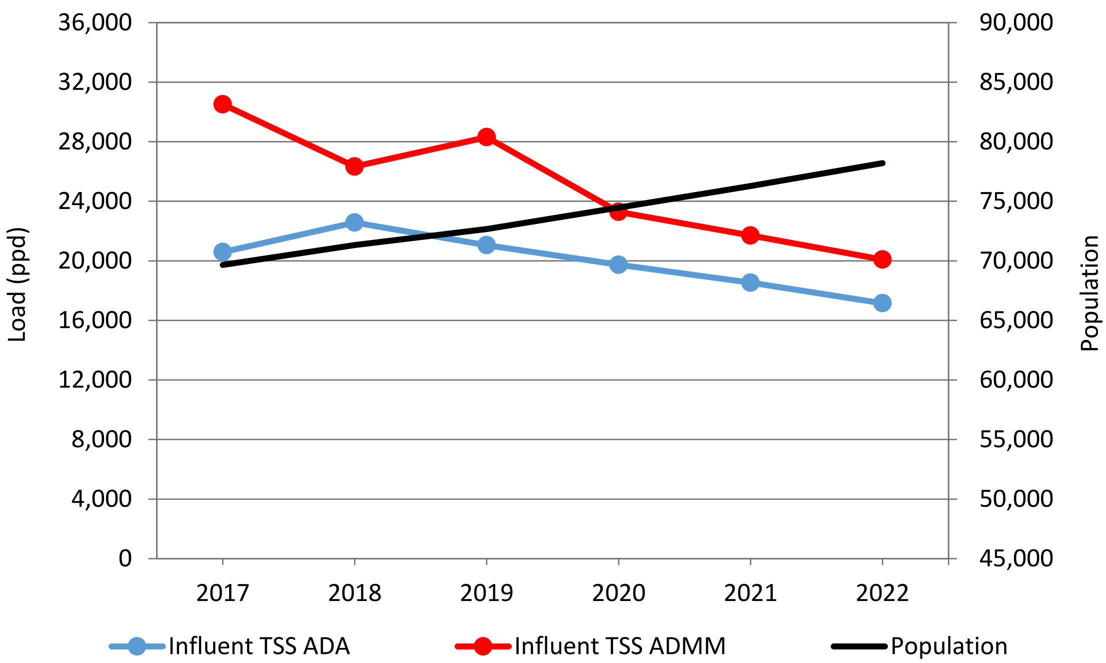


Figure 1.17 Influent TSS Load ADA and ADMM Values from 2017-2022

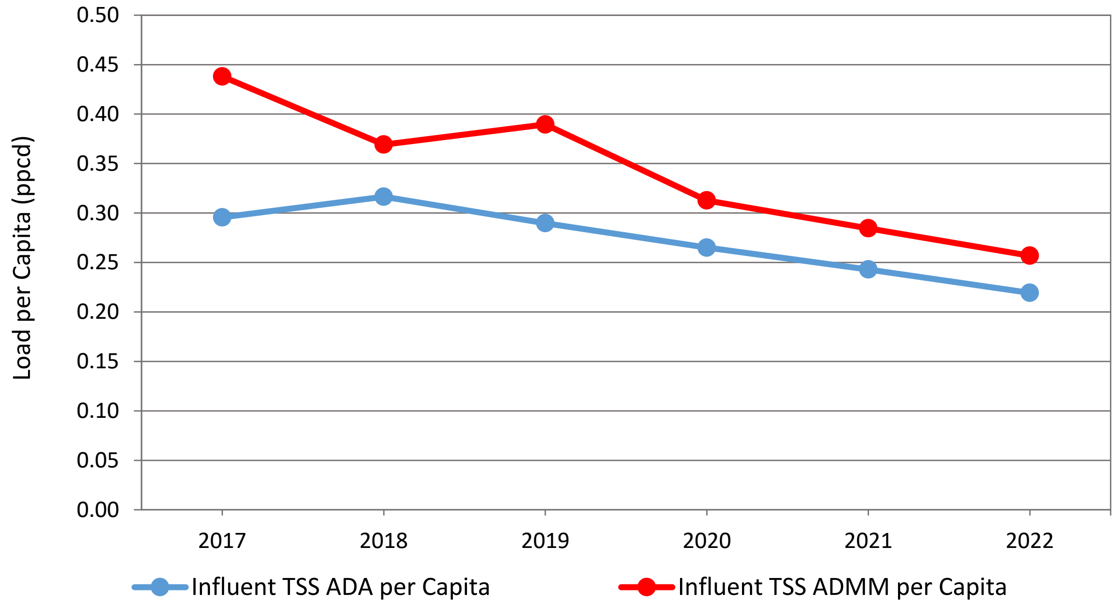


Figure 1.18 Influent TSS Load per Capita ADA and ADMM Values from 2017-2022

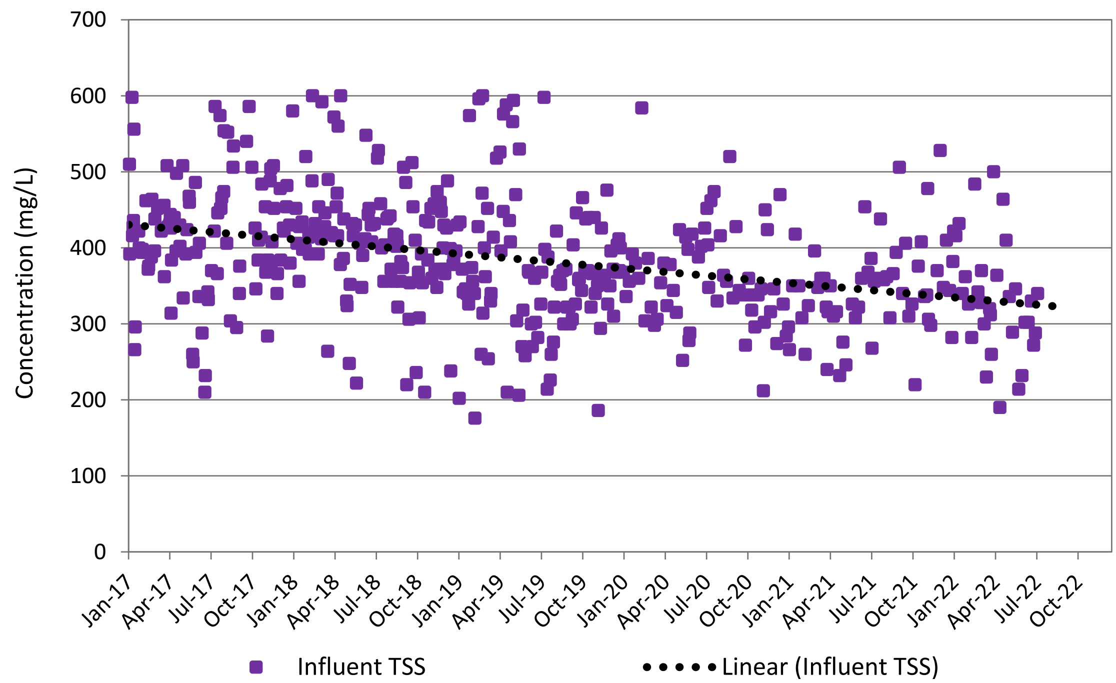


Figure 1.19 Daily Influent TSS Concentrations from 2017-2022

The 2017 to 2022 influent TKN load ADA and ADMM and per capita ADA and ADMM values are plotted in Figures 1.20 and 1.21, respectively. A stepwise drop in TKN loads is observed between the 2019 and 2020 average values. This stepwise drop is also seen between the NH_4 and TP 2019 and 2020 average load values shown in Figures 1.22 and 1.23 and Figures 1.24 and 1.25, respectively.

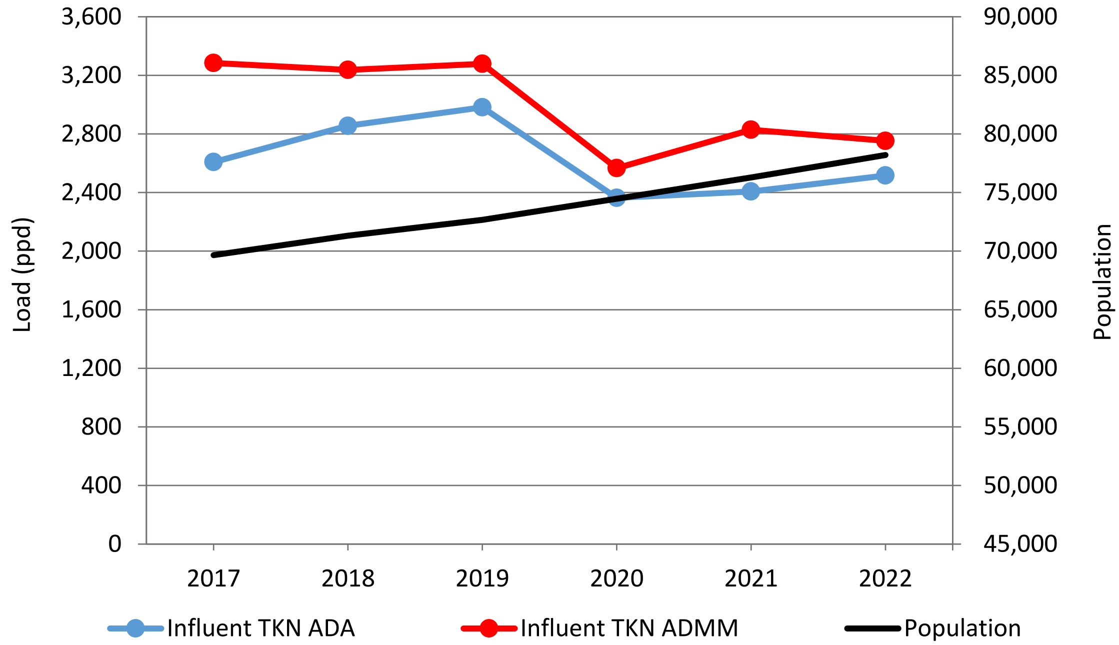


Figure 1.20 Influent TKN Load ADA and ADMM Values from 2017-2022

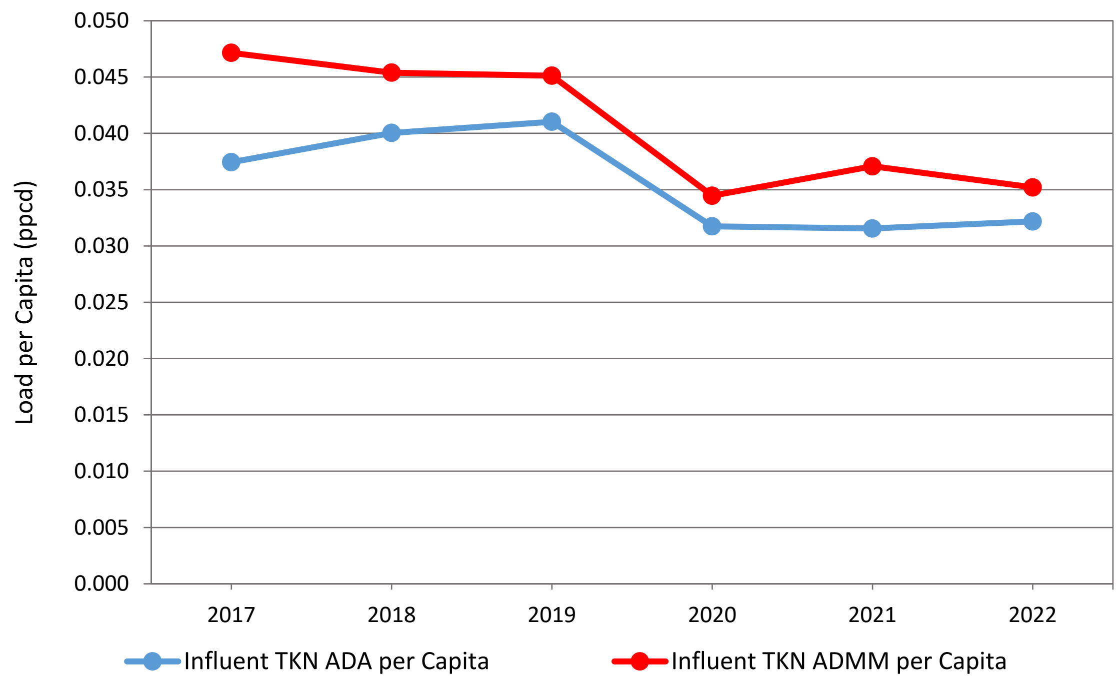


Figure 1.21 Influent TKN Load per Capita ADA and ADMM Values from 2017-2022

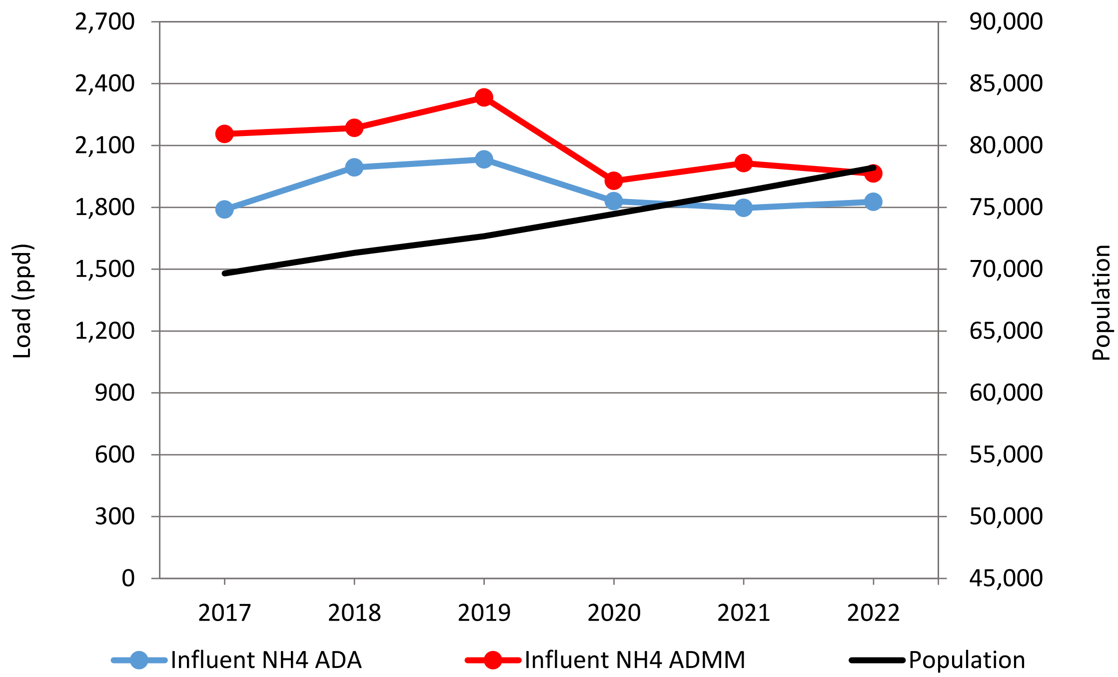


Figure 1.22 Influent NH4 Load ADA and ADMM Values from 2017-2022

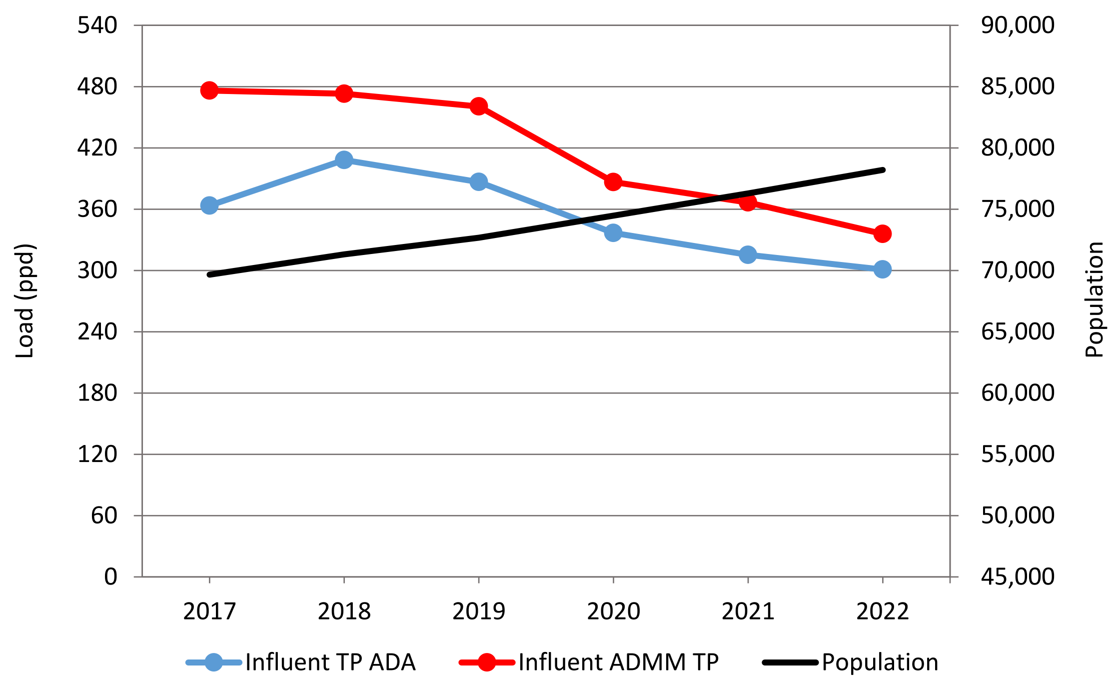


Figure 1.23 Influent TP Load ADA and ADMM Values from 2017-2022

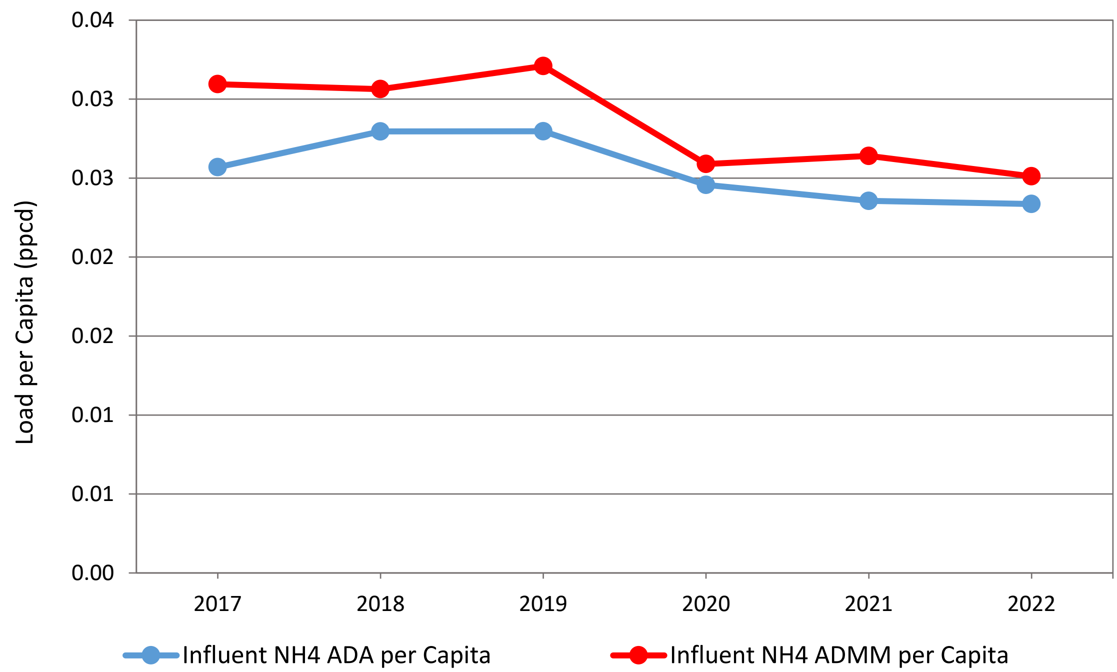


Figure 1.24 Influent NH4 Load per Capita ADA and ADMM Values from 2017-2022

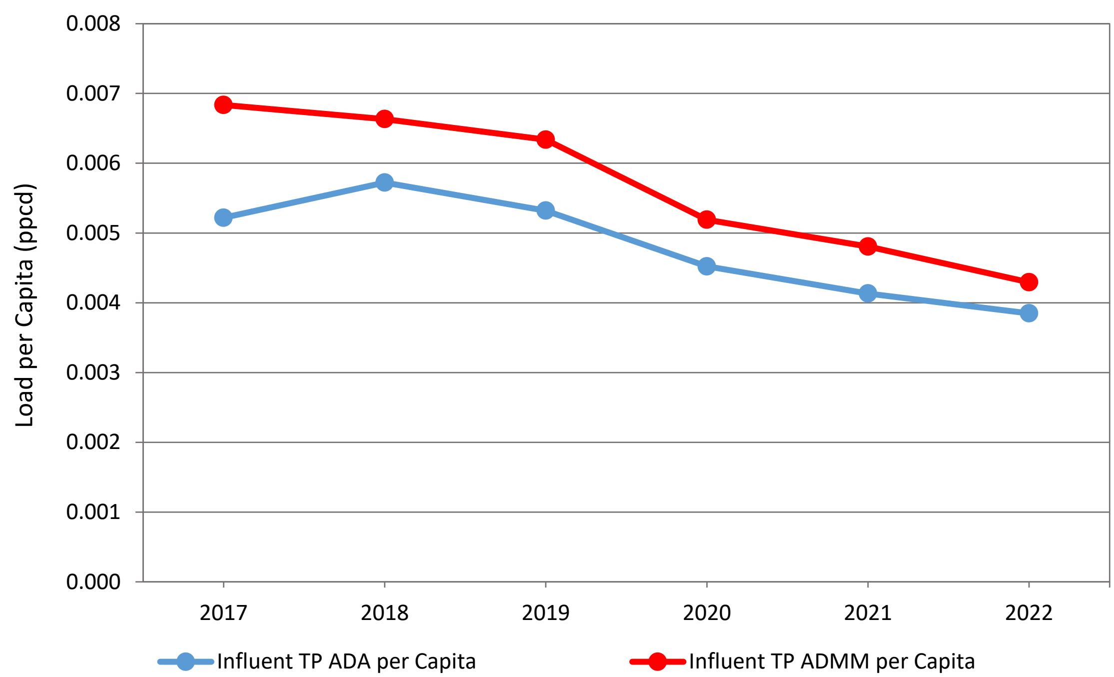


Figure 1.25 Influent TP Load per Capita ADA and ADMM Values from 2017-2022

1.2.3.1 Industrial Load Changes

This stepwise drop may possibly be related to two industrial contributors leaving Broomfield in 2019 and 2020. Wastewater flows from Sandoz, a pharmaceutical company, and Teilhaber, a shelving, rack, and platform manufacturer, were last recorded on August 5, 2019, and July 8, 2020, respectively, and it is assumed that these dates are representative of when their WRF contributions ceased. Sandoz and Teilhaber wastewater samples were tested for BOD_5, chemical oxygen demand (COD), TSS, and TP concentrations. Though flow values were measured at later dates as indicated above, the last recorded sample dates for testing of these constituents were July 17, 2019, and October 2, 2019, for Sandoz and Teilhaber, respectively.

The maximum constituent loads contributed by each industry recorded between 2017 and the last sample date were compared to 2017 to 2019 average WRF influent loads. The maximum loads from Sandoz and Teilhaber were less than one percent of the average WRF influent loads, and the largest listed TP load (about 4 ppd) is less than 10 percent of the magnitude of the observed stepwise drop (the difference between the 2019 and 2020 TP ADA loads is about 50 ppd). While Sandoz and Teilhaber nitrogen data is unknown, the existing data do not appear to indicate that these industries were large enough contributors to account entirely for the observed stepwise decreases.

1.2.4 Basis of Projection

The basis of projection for each parameter of interest was selected from the per capita ADA and ADMM values presented above. Due to the stepwise decrease observed between the 2019 and 2020 values for nutrient loads, it is recommended removing 2017 to 2019 values as not representative of current or trending values. It was also recommended to remove 2022 values as they did not encompass a full set of annual data at the time of analysis. It is recommended that for each condition (ADA, ADMM) and each parameter (flow, BOD_5, TSS, TKN, NH_4, TP), the selection of the maximum value between the 2020 and 2021 value as the basis of projection. The recommended basis of projection is listed in Table 1.1.

Table 1.1 also compares the selected average per capita values to (1) those estimated and selected by Carollo in November 2020 as part of a carbon addition study and (2) typical domestic wastewater utility values as found by the Water Environment Federation's (WEF) *Design of Water Resource Recovery Facilities Manual of Practice No. 8* (MOP 8). The values selected for this Utility Plan are lower than those reviewed previously with Broomfield in November 2020. This is reflective of the downward trend in constituent loading.

Table 1.1 Flow and Load Basis of Projections

Parameter	Condition	2022 Master Plan per Capita Flows/Loads (gpcd or ppcd) Basis of Projections	Prior Nov. 2020 Analysis per Capita Flow/Load Estimates (gpcd or ppcd)	WEF MOP 8 per Capita Values (gpcd or ppcd)
Flow	ADA	87	94	70 to 130
	ADMM	107	127	
BOD_5	ADA	0.19	0.21	0.11 to 0.20
	ADMM	0.23	0.26	
TSS	ADA	0.27	0.33	0.13 to 0.33
	ADMM	0.31	0.44	
TKN	ADA	0.032	0.042	Not Available
	ADMM	0.037	0.046	
NH_4	ADA	0.025	0.029	0.011 to 0.026
	ADMM	0.026	0.034	
TP	ADA	0.005	0.006	0.003 to 0.010
	ADMM	0.005	0.007	

Notes:
ppcd pounds per capita per day

For planning purposes, peaking factors were also evaluated. The BWRF's design influent non-equalized peak hour flow (PHF) is 31.2 million gallons per day (mgd). This PHF capacity is equivalent to a 2.6 peaking factor above current rated ADMM flow (ADMMF) capacity (12 mgd). It is noted that Broomfield's industrial pretreatment program has issued permits to approximately 600 sump pumps for discharge to the sewer system as part of City code. Broomfield does not have a complete count of sump pumps since permitting was not required prior to 2021.

Hourly data are not trended or available for historic influent flow peak analysis. Daily cumulative flow and peak instantaneous values are available, as shown in Figure 1.26. The peak instantaneous values trend with the daily cumulative values, overall remaining relatively stable and not displaying either an evident increasing or decreasing trend over the last 5 years. This peak instantaneous data was used to complete the peak analysis. The maximum peak instantaneous influent flow recorded between 2017 and the time of this analysis was 23.9 mgd on July 26, 2018.

Instantaneous peak flow data and the ratio of the peaking factor over the cumulative daily flow are summarized in Table 1.2. A percentile plot showing the frequency of occurrence of peak and daily flows is shown in Figure 1.27. In general, peak instantaneous flow is roughly 200 percent of the daily flow with the maximum ratio at 336 percent.

Table 1.2 Peak Flow Data and Peaking Factors

Value	Peak Instantaneous Flow (mgd)	Daily Flow (mgd)	Peaking Factor(1)
Maximum	23.9	12.2	3.4
99th Percentile	16.0	8.3	2.4
98th Percentile	14.8	7.8	2.2
95th Percentile	13.3	7.4	2.0
Average	11.1	6.4	1.7

Notes:
(1) Peaking factors represent calendar day comparisons, rather than percentile comparisons. For instance, peak flow of 23.9 mgd did not occur on the maximum daily flow of 12.2 mgd.

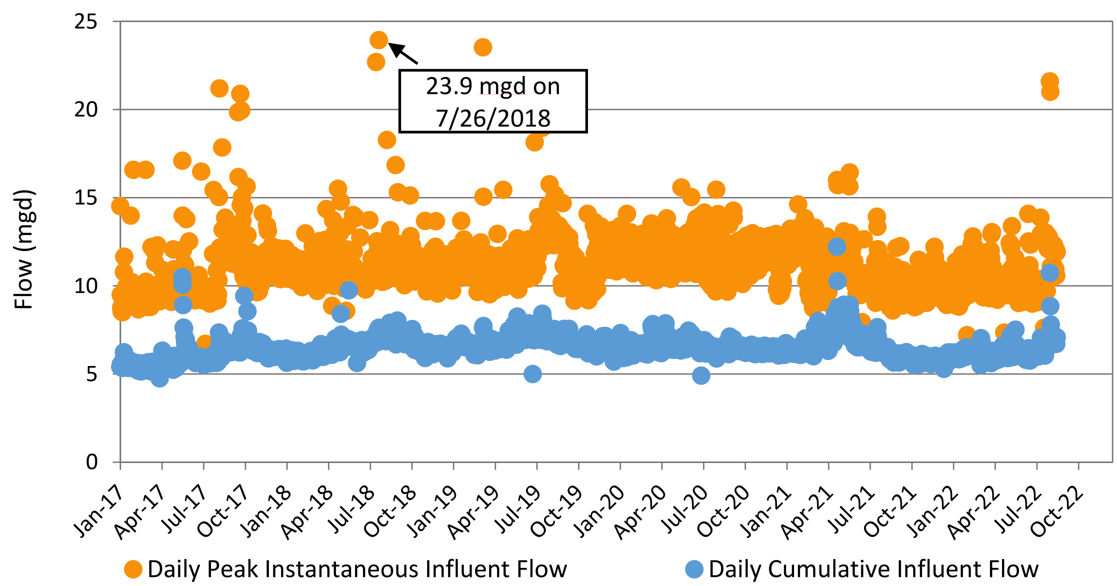


Figure 1.26 Daily Peak Instantaneous and Daily Cumulative Influent Flow from 2017-2022

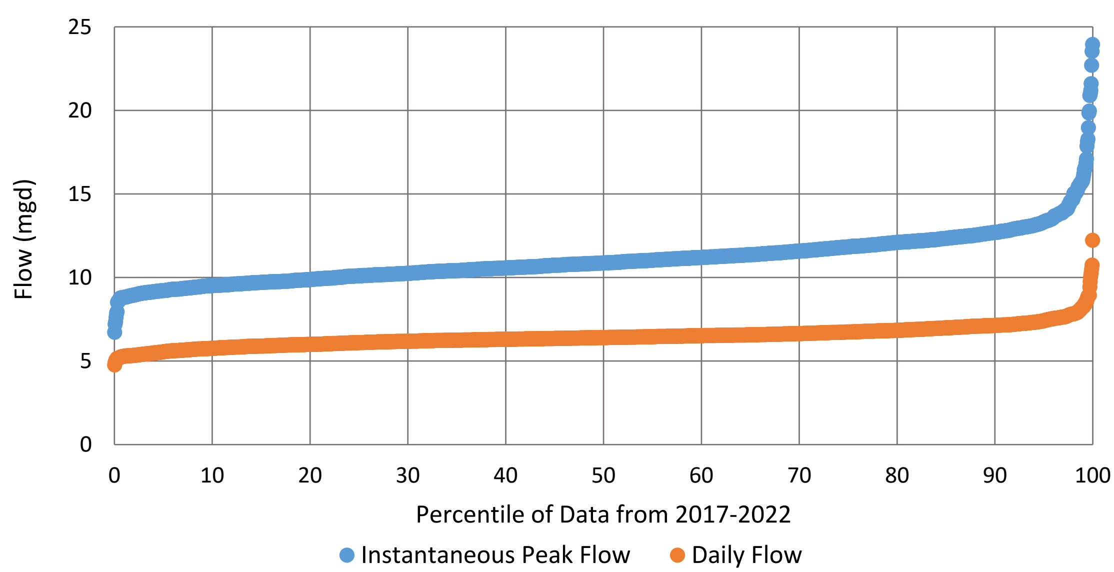


Figure 1.27 Percentile Plot of Flows from 2017-2022

1.2.5 Projected Wastewater Flows and Loads

1.2.5.1 Projected Population

The Broomfield Planning Division provided projected population numbers for 2022 to 2050 for this study, as shown in Table 1.3. These are updated gross population projections as of June 2023 based on permitted buildings. The population grows more rapidly in the near term and nears a buildout population of 128,000.

Table 1.3 Projected Population

Year	Gross Population Projected Based on Permitted Buildings (June 2023)
2023	87,617
2024	91,937
2025	95,400
2026	97,719
2027	102,019
2028	103,595
2029	106,195
2030	107,932
2031	110,450
2032	111,760
2033	113,142
2034	113,645
2035	115,253
2036	116,424
2037	118,082
2038	119,378
2039	120,521
2040	121,864
2041	122,011
2042	122,994
2043	123,361
2044	123,654
2045	124,488
2046	125,207
2047	126,022
2048	126,169
2049	126,984
2050	127,799

1.2.5.2 Projected Flows and Loads

To project Broomfield's flows and loads, the basis of projection per capita values listed in Table 1.1 were multiplied by the projected population values listed in Table 1.2. The ADMM projections for flow and BOD_5 are plotted in Figures 1.28 and 1.29.

Per CDPHE requirements, domestic wastewater treatment works are required to (1) initiate engineering and financial planning for expansion whenever the ADMM throughput and treatment reaches 80 percent of design capacity, and (2) commence construction of such expansion whenever ADMM throughput reaches 95 percent of design capacity. Under the current population projections, flow was not projected to exceed the 95 percent expansion trigger, and BOD_5 was expected to hover around that trigger but not exceed the permitted load. Under the updated population projections, flow is predicted to hit the 95 percent trigger in 2033 and then exceed the current permitted flow of 12 mgd in 2035. This higher population growth projection may come with increased density, and correspondingly result in lower per capita flows. BOD_5 is predicated to hit that trigger earlier, by 2029, and then exceed the current permitted load of 23,108 ppd in 2030.

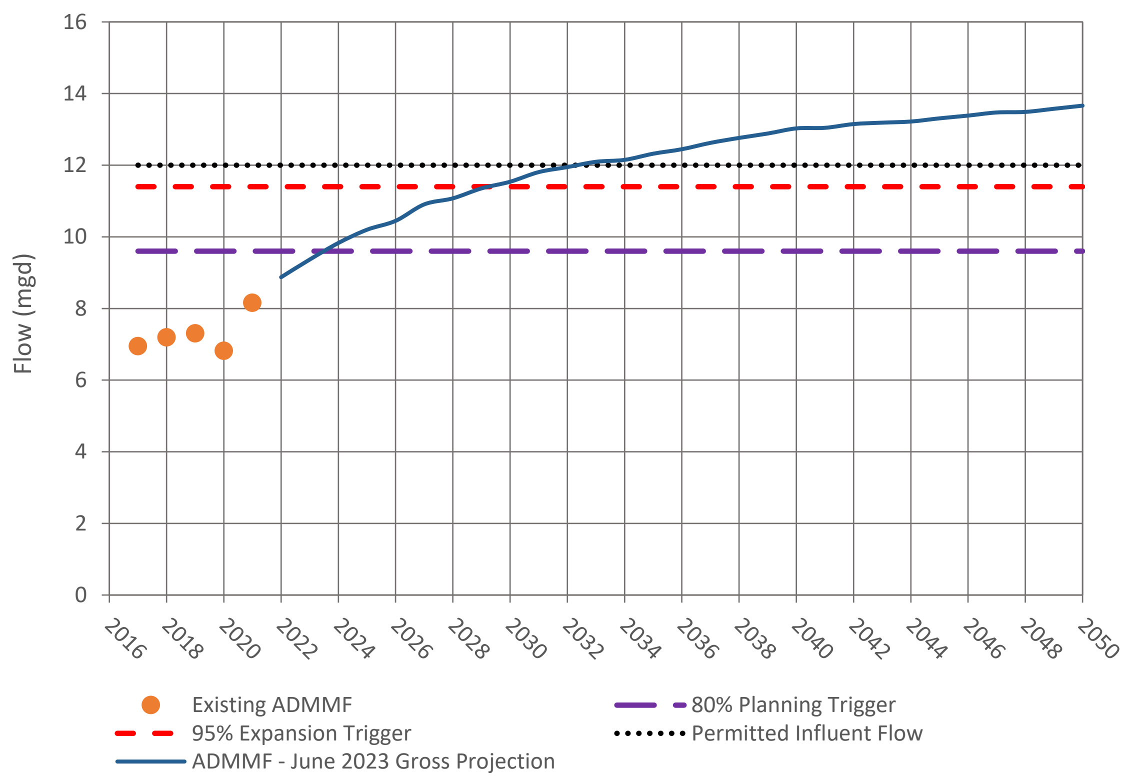


Figure 1.28 Projected Influent Flow from 2022-2043

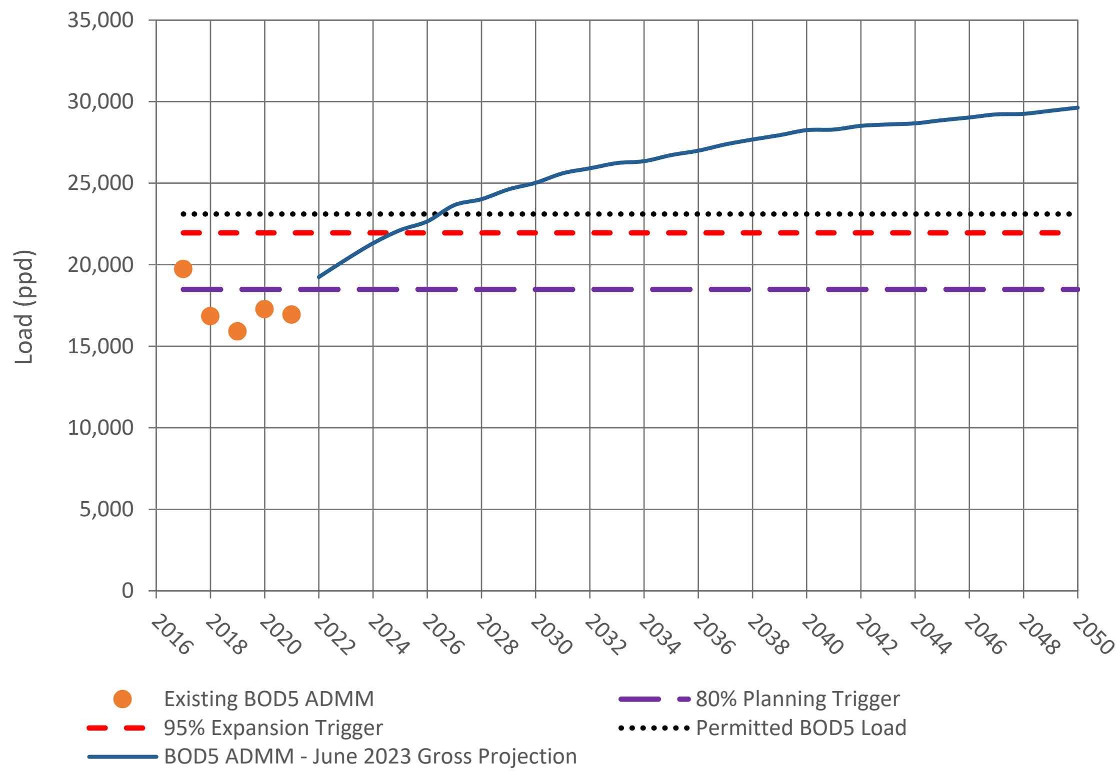


Figure 1.29 Projected Influent BOD Loading from 2022-2043

1.3 Regulatory Drivers Assessment

The WRF treats and discharges domestic and industrial wastewater in compliance with state and federal regulations to protect human health and water quality-related classified uses in Big Dry Creek and the Great Western Reservoir (GWR). These regulatory requirements change over time through revisions of current regulations, the implementation of new water quality standards, or the addition of new facilities that can alter existing assimilative capacity allocations. The following sections present current, future, and other potential water quality regulatory drivers that are expected to impact near and long-term treatment planning activities for the WRF.

1.3.1 Current Discharge Permit and Renewal

The WRF is permitted under Colorado Discharge Permit System (CDPS) for domestic wastewater treatment system CDPS Permit Number CO-0026409. The most recent permit under the CDPHE Water Quality Control Division (WQCD) was last issued in February 2022 and is set to expire December 31, 2024.

The permit includes a permitted hydraulic capacity of 12 mgd ADMMF and organic loading of 23,018 ppd of BOD_5, as approved by CDPHE in Site Location Approval No. 4561 | ES.14.SA.00494.

Current permit limits in effect are summarized in Table 1.4. In addition to these limits, the permit requires reporting of effluent temperature, sulfide as hydrogen sulfide (H_2S), and metals, which are detailed later in this report. All limits apply to both outfalls, unless otherwise indicated.

Table 1.4 Current WRF Discharge Permit Limitations for Big Dry Creek and GWR

Effluent Parameters	Units	Effluent Limitations	
Effluent Flow	mgd	12	
E. coli	#/100 mL	205 (30-day average) 410 (7-day average)	
Total Residual Chlorine	mg/L	0.012 (30-day average) 0.019 (DM)	
BOD_5	mg/L	25 (30-day average) 40 (7-day average)	
TSS	mg/L	30 (30-day average) 45 (7-day average)	
pH	SU	6.5-9.0	
Oil and Grease	mg/L	10 (DM)	
Total Inorganic Nitrogen (TIN)	mg/L	Until June 30, 2024, 31 (DM) Beginning July 1, 2024, 14 (DM), 15 (running annual median), 20 (95th percentile)	
TP	mg/L	1.0 (running annual median) 2.5 (95th percentile)	
Chronic Toxicity	WET	NOEC or IC25≥ IWC	
Ammonia		**30-day Average**	**DM**
January	mg/L	5.2	18
February	mg/L	5.3	18
March	mg/L	5.1	18
April	mg/L	4.7	13
May	mg/L	3.7	20
June	mg/L	3.3	8.1
July	mg/L	3.1	21
August	mg/L	3.1	23
September	mg/L	3.2	24
October	mg/L	3.4	24
November	mg/L	3.8	20
December	mg/L	4.7	20

Notes:

DM	daily maximum	mL	milliliter
IWC	instream waste concentration	NOEC	no observed effect concentration
µg/L	micrograms per liter	SU	Standard Unit
mg/L	milligrams per liter	WET	whole effluent toxicity

1.3.2 Receiving Water

The WRF has two discharge points – Big Dry Creek (Outfall 001B), Segment COSPBD01 and Great Western Reservoir (Outfall 002A), Segment COSPBD03. Per the WQCD Fact Sheet (November 27, 2019), ambient water quality data for Big Dry Creek does not currently exist, and the WRF was required to establish an in-stream monitoring station within two miles upstream of the discharge point by March 31, 2020, per the last discharge permit.

A mixing zone study completed in 2006 for GWR indicated that due to the high dilution factors (86 to 98 percent) of the receiving water body, the effluent requirements for Big Dry Creek were much more stringent. For the most part, achieving the limits required by the Big Dry Creek outfall is adequate for GWR. Selenium and radionuclides are two exceptions.

The selenium standard applied to GWR is more stringent than the site-specific selenium standards applied to the Big Dry Creek; the selenium standards for GWR are 4.6 µg/L (chronic) and 18.4 µg/L (acute). The parameter evaluation listed in the most recent permit fact sheet indicates that, based on the available data, effluent limitations were not necessary at this time. However, a monitoring requirement was added to collect enough data to conduct a reasonable potential analysis at the next permit renewal.

In addition to the statewide basic standards for radionuclides, there are site specific radionuclide standards for GWR listed in Regulation 38. Per the statement of basis and purpose of the 1989 rulemaking conducted for GWR, the site-specific radionuclide standards were adopted to ensure that appropriate classifications and standards were in place for an NPDES permit for the Rocky Flats plant. Due to the legacy land use of the Rocky Flats site, and surface and groundwater leaving the site, the WQCD has made a qualitative reasonable potential determination that additional radionuclide monitoring is necessary for the BWRF.

1.3.3 Reuse and Potable Reuse

The BWRF currently diverts a portion of wastewater effluent to tertiary filtration for non-potable reuse, primarily via landscape irrigation. This non-potable reuse water is subject to the regulatory requirements of CDPHE Regulation 84. Broomfield is considering steps towards direct potable reuse (DPR) or indirect potable reuse (IPR) as a compelling option to increase water supply resilience and portfolio diversity. On November 14, 2022, CDPHE approved Regulation 11 to define specific regulatory requirements for DPR in Colorado.

Broomfield's considerations for IPR or DPR include the following:

- Location of an advanced water purification facility – at the WRF or at the Water Treatment Facility.
- Treatment options include carbon-based advanced treatment and/or ion exchange-based advanced treatment that replace reverse osmosis, in avoidance of the challenge of disposing large volumes of concentrate.
- Potential challenges to address include high nitrate concentrations in the treated wastewater, salinity management, and distribution approaches.
- Essential efforts to the success of any potable reuse projects include enhanced source control, public education and outreach, and pilot or demonstration studies.

Chapter 6 – Potable Reuse Feasibility Study of this Master Plan includes an evaluation of the feasibility of potable reuse for Broomfield.

1.3.4 Current Compliance Review

1.3.4.1 Regulation 85 and Voluntary Incentive Program

In October 2017, the Water Quality Control Commission (WQCC) adopted a Voluntary Incentive Program (Incentive Program) for early nutrient reductions. With the Incentive Program, facilities can make early nutrient reductions to levels below the Regulation 85 limits in exchange for an extended compliance schedule that will be applied to the facility's first permit renewal after 2027. The program is performance based, where facilities that reduce effluent nutrient loads below the Regulation 85 limits between 2018 and 2027 receive an extended compliance schedule for meeting water quality-based effluent limits (WQBEL) anticipated under Regulation 31.

Incentive credits are calculated pursuant to WQCC Policy 17-1 and can be earned for up to a maximum of 10 years for decreasing both total nitrogen (TN) and TP. Achieving the full 10 years of credit could delay the effective date of Regulation 31 limits to beyond 2037 for TN and TP compliance (see Regulation 31 section below).

The WRF completed the required Incentive Program enrollment form for CDPHE in 2018 and must submit an annual report to the WQCD each year stating annual median values for TIN and TP. The WRF is on track to gain incentive credits (see Table 1.5). Current performance indicates that nearly full credit could be achieved to delay Regulation 31 implementation assuming improved performance in parallel with the DM TIN limit that goes into effect in 2024.

CDPHE reports values received officially from program applicants at their website (https://cdphe.colorado.gov/nutrients-incentive-program). Broomfield does not have submitted results for 2018 or 2019 and should reach out to resolve this based on the summary below, as credits for TP are warranted in these years. As of May 2023, this was not corrected on the CDPHE website.

Table 1.5 Regulation 85 Incentive Credits Summary and Projections

Year	Annual Median Concentrations(1)		Incentive Credits Earned	
	TIN (mg/L)	TP (mg/L)	TIN (month)	TP (months)
2018	15.5	0.12 (2)	0	12
2019	15.9	0.12 (2)	0	12
2020	15.4	0.08	0	12
2021	14.1	0.10	1.35	12
2022 (projected)	14	0.1	1.5	12
2023 (projected)	13	0.1	3	12
2024 (projected)	12	0.1	4.5	12
2025 (projected)	12	0.1	4.5	12
2026 (projected)	12	0.1	4.5	12
2027 (projected)	12	0.1	4.5	12
Total Months			23.9	120
Eligible Months			23	90
Eligible Years			1.91	7.5
Total Years			**9.4**	

Notes:
(1) Estimated annual median TIN and TP for 2022-2027 based on historical data and attainable performance assuming MicroC® chemical addition is in service by spring 2023.
(2) 2018 and 2019 data are not in CDPHE's database. Carollo recommends confirming that these data were submitted and working with CDPHE to update their database. (https://cdphe.colorado.gov/nutrients-incentive-program)

Whole Effluent Toxicity

The WQCD established the use of WET testing to identify and control toxic discharges from wastewater treatment facilities. WET testing is used to ensure that contaminants in the discharge are neither harmful for the beneficial use or toxic to humans, animals, plants, or aquatic life. This testing is anticipated to continue for the foreseeable future. The BWRF has not shown toxicity in the survivability results of the quarterly WET tests.

Ammonia

Effluent ammonia has differential monthly average and DM limits (see Table 1.4). Since the new effluent limits were issued in February 2022, effluent performance has been maintained below 2.5 mg/L of ammonia. Balancing ammonia removal with TIN removal will be important with the implementation of the DM TIN limit.

1.3.4.2 Water Quality Parameters Relevant in Future Permit Renewals

Temperature

In compliance with the permit requirements, the WRF has installed continuous ambient temperature monitoring equipment. As a result, the facility will likely receive temperature limits as part of a future permit renewal if the decision is made that there is reasonable potential for the facility to cause or contribute to an exceedance of the water quality standard for temperature.

The WRF effluent temperature plotted against the maximum weekly average temperature (MWAT) instream temperature standards for Big Dry Creek are shown in Figure 1.30. The comparison between effluent temperature and standards indicates that compliance challenges will arise in the winter season for weekly limits (chronic standards). The in-stream standard MWAT for Big Dry Creek is 12.1 degrees Celsius (C), while effluent temperatures in this time frame are as high as 19 degrees C. The DM limits (acute standards) appear to be 5 to 10 degrees higher than historical effluent temperatures.

The Fact Sheet to Permit Number CO0026409, dated November 27, 2019, states the following regarding temperature effluent limits: "Temperature: A WQBEL for temperature can only be calculated if there is representative data, in the proper form, to determine what the background Maximum Weekly Average Temperature and DM ambient temperatures are. As this data is not available from Broomfield, Westminster, or Northglenn WRFs at this time, the temperature limitation will be set at the water quality standard and will be revisited in the future when representative temperature data becomes available." Since more data are becoming available, it is likely that reductions in winter effluent temperatures will be required.

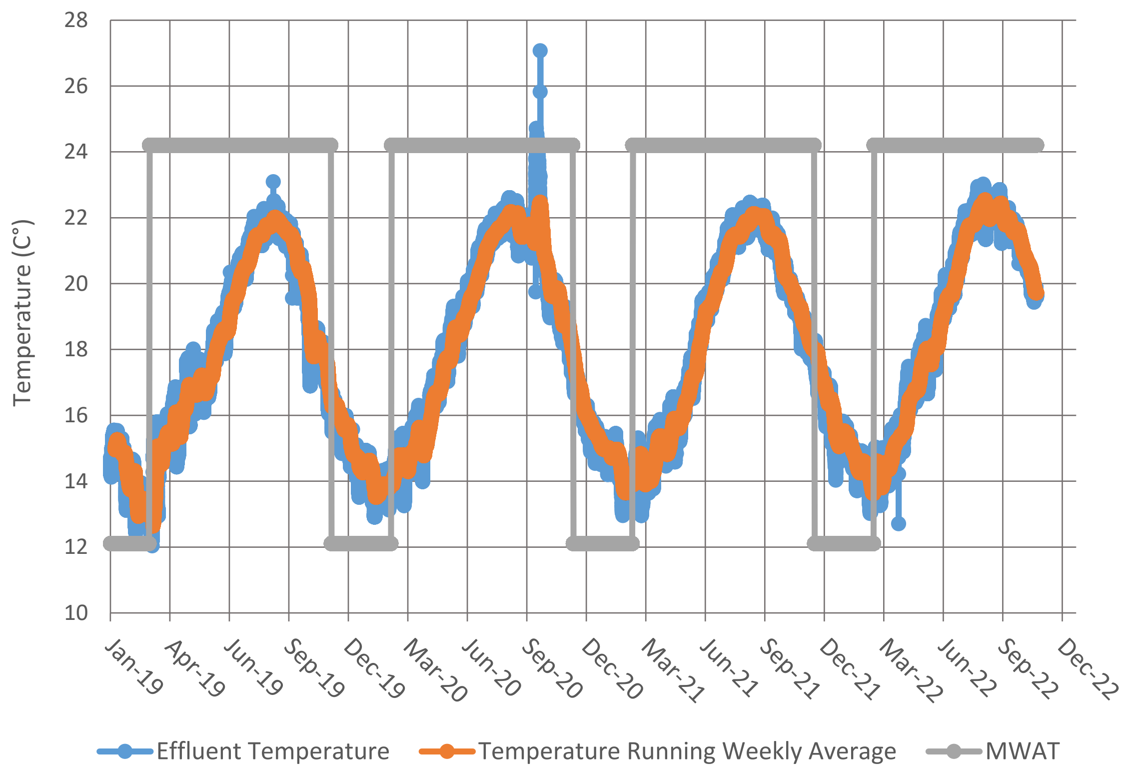


Figure 1.30 BWRF Effluent Temperature and Big Dry Creek MWAT Standards

Carollo recommends Broomfield consider potential temperature mitigation options.

Metals and Other Non-Metals

In compliance with the permit requirements, the BWRF is currently monitoring effluent metals such as: Arsenic (As), Beryllium (Be), Cadmium (Cd), Copper (Cu), Lead (Pb), Mercury (Hg), Manganese (Mn), Molybdenum (Mo), and Boron (B). They also monitor non-metals such as Cyanide (CN), Selenium (Se), sulfide as H_2S, sulfate, and nonylphenol. WQBELs and reporting requirements for each of these constituents are summarized in Table 1.6.

A review of effluent metal concentrations in recent years shows that none of the constituents approach the WQBEL and thus are not anticipated to result in a future limit in the next permit based on data reviewed and available to date. Where values are report only, it is possible that the monitoring results may affect future permit requirements.

Table 1.6 WQBELs for Metals with Monitoring Requirements in Current Permit

Effluent Parameter	Units	30-day Average	DM
As, total recoverable	µg/L	Report	
Be, total recoverable	µg/L	Report	
Cd, dissolved	µg/L	Report	Report
Cu, dissolved, beginning July 1, 2021	µg/L	27	45
CN, weak acid dissociable	µg/L		Report
Fe, total recoverable	µg/L	Report	
Fe, dissolved	µg/L	Report	

Effluent Parameter	Units	30-day Average	DM
Mn, dissolved	µg/L	Report	
Mo, total recoverable	µg/L	Report	
Hg, Total, beginning July 1, 2021	µg/L	0.010	
Se, dissolved	µg/L	Report	Report
B, total	mg/L	Report	
Sulfide as H_2S	mg/L	Report	
Sulfate	mg/L	Report	
Nonylphenol	µg/L	Report	Report

Radionuclides

Monitoring requirements for radioactive materials are summarized in Table 1.7. It is possible that the monitoring results may affect future permit requirements.

Table 1.7 Radioactive Materials Water Quality Monitoring

Effluent Parameter	Units	30-Day Average Value
Americium 241	pCi/L	Report
Cesium 134	pCi/L	Report
Curium(1)	pCi/L	Report
Neptunium(1)	pCiL	Report
Plutonium 239 and 240	pCi/L	Report
Radiation, gross alpha(1)	pCi/L	Report
Radiation, gross beta(1)	pCi/L	Report
Radium 226 and 228	pCi/L	Report
Strontium 90	pCi/L	Report
Thorium 230 and 232	pCi/L	Report
Uranium	pCi/L	Report
Tritium	pCi/L	Report

Notes:
(1) Applicable to Outfall 002A only.
pCi/L picocuries per liter

Per- and Polyfluoroalkyl Substances in Effluent Discharges

Per- and polyfluoroalkyl substances (PFAS) are a large group of synthetic fluorinated chemicals that have unique physical and chemical properties. PFAS are oil and water repellent, chemically, biologically, and thermally stable and therefore are highly persistent and mobile in the environment. Due to decades of extensive use of these chemicals and their recalcitrance to chemical and biological degradation, PFAS are now detected throughout the environment in soils, air, water, food, consumer products, and human blood.

Perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) are the two PFAS compounds of most research and regulatory focus due to their potential association with several toxicological end points, including kidney cancer, testicular cancer, and high cholesterol. For this reason, the Environmental Protection Agency's (EPA) has been intending to set standards for these two PFAS compounds across the different stages of the water cycle. Beyond PFOA and PFOS, it has been estimated that the PFAS family may include over 12,000 chemical substances. PFOA and PFOS have been phased out in the United States under the 2010 PFOA Stewardship Program and are replaced with short-chain perfluorinated and polyfluorinated compounds, and perfluoroethers (e.g., GenX chemicals). Shorter-chain alternative PFAS have been utilized due to their shorter half-lives in the human body and relatively lower toxicity, but precaution is warranted based on the similarity of their environmental persistence to that of PFOA and PFOS. In addition to adverse human health effects, PFAS in wastewater effluent may pose a hazard to aquatic ecosystems. For instance, the Australian PFAS National Environmental Management Plan recommends a guideline of 0.23 nanograms per liter (ng/L) for PFOS for the protection of 99 percent species in aquatic ecosystems.

The last year has seen significant changes in USEPA approach to PFAS regulation for drinking water. On June 15, 2022, the EPA issued interim updated drinking water health advisories (HA) for PFOA (0.004 ng/L) and PFOS (0.02 ng/L) that replace those EPA issued in 2016 (Table 1.8). The updated HAs, which are based on new science and consider lifetime exposure, indicate that some negative health effects (e.g., developmental, liver, immune, thyroid effects) may occur at PFOA and PFOS concentrations near zero. At the same time, the EPA also issued final lifetime HAs for hexafluoropropylene oxide dimer acid (HFPO-DA of GenX) (10 ng/L) and perfluorobutanesulfonic acid (PFBS) (2,000 ng/L). In chemical and product manufacturing, GenX chemicals are considered a replacement for PFOA, and PFBS a replacement for PFOS. Regardless public and utilities' attention and concern surrounding PFAS, it is important to note that HA levels are non-enforceable and non-regulatory and are not relevant to potential PFAS exposure through wastewater-related pathways, rather, they provide technical information to state agencies and public health officials on human health effects associated with PFAS in drinking water.

Table 1.8 Comparison of 2016 and 2022 Drinking Water PFAS Health Advisories

PFAS Compound	2016 HA (ng/L)	2022 HA (ng/L)	HA Status
PFOA	70	0.004	Interim
PFOS	70	0.02	Interim
HFPO-DA of GenX	Not Established	10	Final
PFBS	Not Established	2,000	Final

On March 14, 2023, the EPA proposed maximum contaminant levels (MCL) and MCL goals for six PFAS compounds. These levels were proposed based on current information on the impacts on human health and ecotoxicity as well as the ability to reliably detect the compounds using current technologies. Proposed MCLs include 4 ng/L for PFOA and PFOS and a Hazard Index (HI) of 1.0 for the following compounds combined: perfluorononanoic acid (PFNA), PFBS, PFHxS, and HFPO-DA (GenX). The HI is a unitless parameter that takes into account the combined impacts on human health of the four compounds and is based on the drinking water health advisory values determined in June 2022. The HI is calculated from the following based on the concentrations of the PFAS compounds (in parts per trillion [ppt]) in the liquid stream.

$$\mathrm{HI} = \frac{[\mathrm{HFPO-DA}]}{[10\ \mathrm{ppt}]} + \frac{[\mathrm{PFBS}]}{[2000\ \mathrm{ppt}]} + \frac{[\mathrm{PFNA}]}{[10\ \mathrm{ppt}]} + \frac{[\mathrm{PFHxS}]}{[9\ \mathrm{ppt}]}$$

It is important to note that the health-based MCL goals for PFOA and PFOS are an non-enforceable concentration of 0 (as listed in Table 1.9), indicating the high human health toxicity of these compounds.

Table 1.9 Proposed MCLs and Goals for Select PFAS Compounds

PFAS Compound	Units	MCL Goal	MCL
PFOA	ng/L (ppt)	0	4
PFOS	ng/L (ppt)	0	4
HFPO-DA of GenX	Unitless	1.0 HI	1.0 HI
PFBS			
PFNA			
PFHxS			

PFAS are ubiquitous in municipal wastewater and biosolids. Major point sources include PFAS-producing or PFAS-using industries such as papermaking, textile mills, and electroplating. However, PFAS have been detected in municipal wastewater even without direct industrial sources. It is suspected that PFAS in non-industrial wastewater may occur in part due to environmental degradation of polyfluorinated microfibers released by laundering water-resistant clothing. Another plausible non-industrial source of PFAS in municipal wastewater is human excretion after oral exposure. Often, a portion of the PFAS in wastewater effluent can be ascribed to PFAS in the community's tap water. PFAS are poorly removed by conventional biological wastewater treatment. On the contrary, the concentrations of certain PFAS (e.g., short-chain perfluoroalkyl acids) increase in treated wastewater effluent due to the biotransformation or oxidation of PFAS precursor compounds.

To date, there are no federal or state-level regulations for PFAS in wastewater effluent. In October 2021, the EPA released *PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024*, which identified specific actions to better protect drinking water supplies, recreational waters, and aquatic ecosystems from PFAS contamination. Key actions include:

- Restrict PFAS discharges from industrial sources through a multi-faceted Effluent Limitations Guidelines program.
- Leverage federally issued National Pollutant Discharge Elimination System (NPDES) permits to reduce PFAS discharges to waterways and issue new guidance to state permitting authorities to address PFAS in NPDES permits.
- Publish final recommended ambient water quality criteria for PFAS to protect aquatic life and human health.

To inform PFAS occurrence, fate and transport through wastewater treatment plants, many states have set requirements to monitor PFAS in wastewater effluent, such as Washington, California, Colorado, Vermont, and North Carolina. In the meantime, Michigan and Wisconsin have established enforceable surface water quality standards for PFOS and PFOA in non-drinking water sources, whereas surface water standards are under development in New Hampshire and New York.

At the WRF, recent permit modifications require monthly monitoring of 25 PFAS compounds in the treated effluent. Monitoring requirements (from January 2022 to December 2023) for PFAS are summarized in Table 1.10. It is possible that the monitoring results may affect future permit requirements.

Table 1.10 PFAS Monitoring Requirements as per Recent Permit Modifications

Effluent Parameter	Units	DM and 30-Day Average Value
Perfluorooctanoic Acid (PFOA)	ng/L	Report
Perfluorobutanoic Acid (PFBA)	ng/L	Report
Perfluorooctanesulfonamide (PFOSA)	ng/L	Report
Perfluoropentanoic Acid (PFPeA)	ng/L	Report
Perfluorohexanoic Acid (PFHxA)	ng/L	Report
Perfluoroheptanoic Acid (PFHpA)	ng/L	Report
Perfluorononanoic Acid (PFNA)	ng/L	Report
Perfluorodecanoic Acid (PFDA)	ng/L	Report
Perfluoroundecanoic Acid (PFUnA)	ng/L	Report
Perfluorododecanoic Acid (PFDoA)	ng/L	Report
Perfluorotridecanoic Acid (PFTrDA)	ng/L	Report
Perfluorotetradecanoic Acid (PFTeDA)	ng/L	Report
2-[N-ethylperfluorooctane sulfonamido] Acetic Acid (NEtFOSAA)	ng/L	Report
2-[N-methylperfluorooctane sulfonamido] Acetic Acid (NMeFOSAA)	ng/L	Report
Perfluorobutanesulfonic acid (PFBS)	ng/L	Report
Perfluorodecanesulfonic acid (PFDS)	ng/L	Report
Perfluoroheptanesulfonic acid (PFHpS)	ng/L	Report
Perfluorohexanesulfonic acid (PFHxS)	ng/L	Report
Perfluorooctanesulfonic acid (PFOS)	ng/L	Report
4:2 Fluorotelomer sulfonic acid (4:2 FTS)	ng/L	Report
6:2 Fluorotelomer sulfonic acid (6:2 FTS)	ng/L	Report
8:2 Fluorotelomer sulfonic acid (8:2 FTS)	ng/L	Report
Perfluoropentane sulfonic acid (PFPeS)	ng/L	Report
Perfluorononane sulfonic acid (PFNS)	ng/L	Report
Hexafluoropropylene oxide dimer acid (HFPO-DA)	ng/L	Report
PFAS Sum	ng/L	Report

In addition to the effluent PFAS sampling listed in Table 1.10, BWRF also is required to initiate a PFAS Source Investigation Study under the existing permit. Results of the study are due to CDPHE by June 2024. Per discussion with Broomfield staff, this study is currently underway. Based on data from January 2022 through April 2023 and excluding an unusually high sample in March 2023, PFOA and PFOS average influent concentrations slightly higher than the proposed drinking water MCL (4.3 and 4.7 ng/L, respectively). Since little remediation occurs in wastewater treatment processes, the wastewater PFOA and PFOS concentrations averaged 8.9 and 4.0 ng/L, respectively, in the effluent and concentrations average 6.0 and 1.4 ng/L, respectively, from the reuse effluent. Concentrations of other PFAS were not high enough to exceed the proposed drinking water hazard index as shown in Figure 1.31.

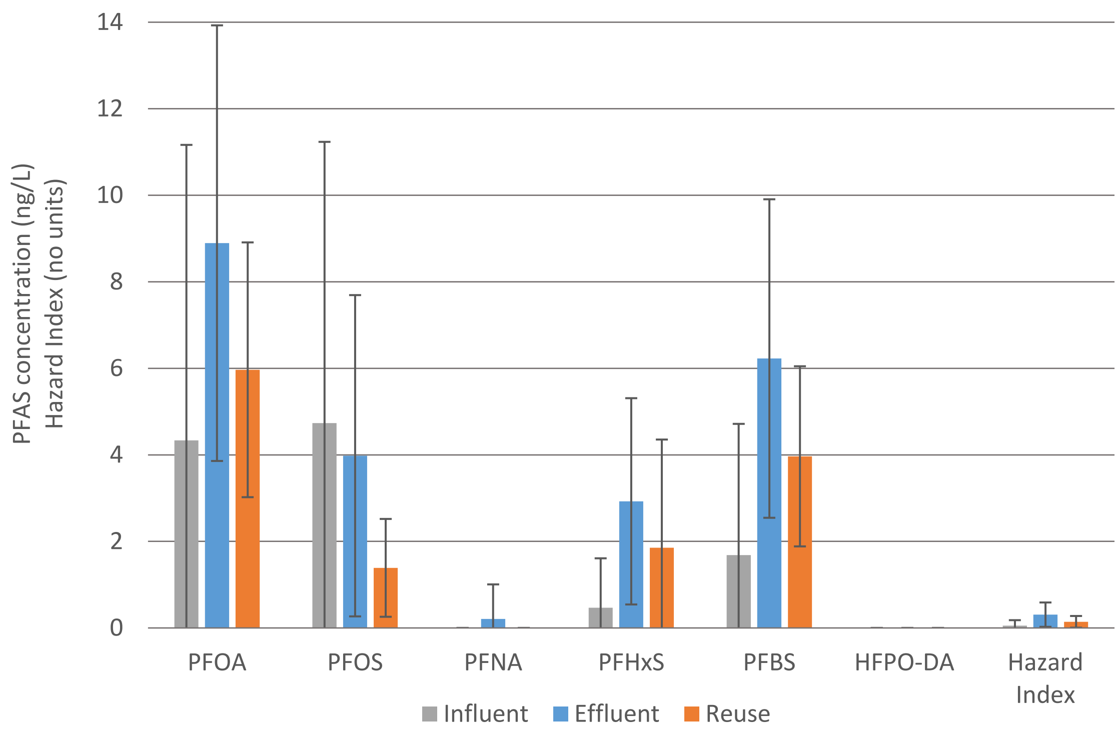


Figure 1.31 Average PFAS and HI Concentrations for Influent, Effluent, and Reuse Streams

1.3.4.3 Future Effluent Regulatory Considerations

Emerging Unregulated Contaminants

A number of trace organic contaminants (TOrC) can be detected in treated domestic wastewater effluents that have been demonstrated to negative effects aquatic and/or human health depending on occurrence concentrations. These contaminants originate in domestic, industrial, or stormwater sources including personal care products, food additives, pharmaceuticals, industrial chemicals, or disinfection byproducts. Concentrations in treated effluent can range from micro to nanograms per liter. While some of the chemicals can be toxic or carcinogenic for humans, concentrations are typically too low and of more immediate concern for discharge locations can be the possible toxic effects of TOrC on aquatic life, specifically endocrine disruption in fish.

Because of the large amount of TOrCs and incomplete data on cause-effect relationships, the EPA has not yet regulated most of these compounds. Instead, standards have been developed for individual compounds, such as nonylphenol and currently perfluorinated compounds (see section above). However, regulations regarding TOrCs discharge from wastewater treatment facilities have been anticipated in the coming one to two decades. Several years ago, other European countries started to require and implement treatment requirements in the form of the so-called fourth treatment step (post tertiary treatment for nutrient removal). The two most typical technologies that are implemented for TOrC removal are either activated carbon sorption or ozonation followed by biologically active filtration.

Two feasible regulatory pathways for TOrC in future years are:

1. Development of regulatory requirements for a small defined group of TOrCs that require treatment upgrades that will then also result in the effective removal of a broader group of TOrCs.
2. The EPA has also contemplated developing "group regulations" for TOrCs instead of proceeding with compound-by-compound regulations.

While timing and nature of these regulations are uncertain, utilities are advised to plan long-term site layouts and finances for treatment upgrades that can accommodate TOrC removal.

Microplastics

Microplastics in wastewater and the environment have become a topic of research over the past years. Of general interest are particles less than 5 millimeters in size and these are categorized into micro-, meso-, and nano plastics. Plastic particles are detected virtually ubiquitously and introduced in wastewater treatment plants through consumer products, stormwater, and other sources.

Microplastics cause possible concerns for aquatic life, but the science and cause-effect relationships are not yet well understood. Detection methods are still under development and not standardized. In the United States, research needs to be further developed before it is clear whether microplastics need to be regulated to mitigate exposure risks, and if that should be the case, for the EPA to develop the necessary data to develop standard methods and the necessary database to conduct risk assessments and develop standards. For this reason, EPA regulations in the United States are not anticipated within the next 10 to 15 years.

Nanoparticles

Nanoparticles are a broad group of organic or inorganic particles in the size range of about 1 to 100 nanometers or larger. These particles originate from various sources in wastewater influent, including consumer products, industrial chemicals, clothing, electronics, or food. In August 2017, the EPA issued a requirement for information collection and reporting for nanomaterials under the Toxic Substances Control Act. This is regarded as a necessary first step for the EPA to start collecting data on this group of chemicals to help with the assessment of whether regulations may be necessary.

Nanoparticles have a high surface area to volume ratio and are therefore often reactive. Few particles are known to be a carcinogen or toxic, for most particles such information is not yet available. Toxicity endpoints are not well understood, occurrence data is difficult to analyze in environmental matrices, and toxicity data is insufficient. For this reason, regulations in the United States from the EPA are not anticipated within the next 10 to 15 years.

Regulation 31 Nutrient Limits

In March 2012, interim numeric nutrient criteria were adopted for TN and TP, but not directly applied to streams and lakes except in limited cases in which TP standards were adopted above discharge locations and in direct use water supply reservoirs. The EPA subsequently approved the interim values for TN and TP in lakes (with additional recommendations) and chlorophyll a in lakes and streams but took no action on stream TN and TP interim values. During the Regulation 85 and Regulation 31 Rulemaking Hearings in October 2017, the WQCC identified an anticipated schedule for nutrients standards adoption as follows:

- 2022 – Statewide adoption of chlorophyll a standards for lakes and streams, and adoption of TN and TP standards for lakes and reservoirs with either Direct Use Water Supply classification or a public swim beach. The chlorophyll a interim numeric values for warm water streams is 150 milligrams per square meter and for warm water lakes is 20 µg/L.
- 2027 – Statewide adoption of TN and TP standards for rivers and remaining lakes.

Anticipated future nutrient limits under CDPHE's Regulation 31, *The Basic Standards and Methodologies for Surface Water* (5 CCR 1002 31 Section 31.17), therefore remain uncertain at this time. The interim nutrient values (effective December 31, 2027, if approved by the EPA) for TN and TP limits in warm water streams are 2.01 mg/L and 0.17 mg/L, respectively. The 2019 Permit Fact Sheet includes a water quality assessment that defines current low flows and instream concentrations of TP and TN. Due to limited assimilative capacity, the calculated effluent limits for Broomfield, Westminster, and Northglenn facilities are essentially equal to the draft water quality standards. The estimated effluent nutrient discharge limits required to meet the Regulation 31 instream standards, assuming the current dilution credit, are summarized in Table 1.10 based on the WQBELs calculated by CDPHE in the 2019 Water Quality Assessment.

It is anticipated that the limits could become effective as annual median limits as early as 2037 assuming 10 years of earned credit under the Incentive Program, or earlier without the credit. Significant WRF improvements will be necessary to meet these limits, and the feasibility of the TN limit compliance is unknown as the fractionation of organic nitrogen (a component of TN but not included in TIN) is unknown but generally is in the range of 2 mg/L in domestic wastewater effluents.

Table 1.11 Total Nitrogen and Total Phosphorus Anticipated Regulation 31 Effluent Limits

Effluent Parameter	Units	Preliminary Standards(1)	Anticipated Regulation 31 Limits(2)
TP	mg/L	0.17	0.18
TN	mg/L	2.01	2.10

Notes:
(1) Interim nutrient standards from Regulation 31.17. Not yet approved by the EPA.
(2) Allowable effluent nutrient concentration per Table A-10a in the BWRF Fact Sheet.

1.3.4.4 Current and Anticipated Regulatory Requirements for Biosolids

This section summarizes the current and future anticipated regulatory requirements for Class B biosolids production in Colorado. Currently, the WRF uses partial anaerobic digestion and composts offsite to meet Class A standards.

Regulation 64 Background

The WQCD adopted *Biosolids Regulation No. 64 (5 CCR 1002-64)* (Regulation 64) (CDPHE, 1993) in November 1993; and was last amended in June 2014. Regulation 64 "establishes requirements, prohibitions, standards, and concentration limitations on the use of biosolids as a fertilizer and/or organic soil amendment in a manner so as to protect the public health and prevent the discharge of pollutants into state waters" (CDPHE, 1993).

Regulation 64 is based on the EPA 40 CFR Part 503 Biosolids Rule, but it is a Colorado-specific rule that governs how biosolids are handled, treated, and applied to land or utilized for public use. The following discussion presents regulatory pathways for beneficial use of biosolids for land application (Class B).

Class A biosolids are a higher-quality product that must meet more stringent pathogen reduction requirements. As a result, Class A biosolids can be distributed for public use without further testing and monitoring. Class B biosolids must still meet certain pathogen reduction requirements, but the limits are lower than those for Class A biosolids. These biosolids cannot be distributed for public use, but they may be land-applied. However, sites that apply Class B biosolids are subject to certain access and food production restrictions.

Class B biosolids require pathogen reduction, vector attraction reduction, and metals concentration limits.

Anticipated Future Biosolids Requirements

As previously discussed, conventional secondary and tertiary treatment processes do not removal or destroy PFAS, whereas a portion of PFAS may partition into sludge. Common sludge handling practices, such as lime treatment, digestion, thermal drying, and composting have little impact on PFAS concentrations. Therefore, PFAS are also ubiquitously present in biosolids. As expected, the concentrations of PFAS in biosolids are generally higher at WRFs where PFAS-producing and/or PFAS-using industries discharge to the sewer collection systems.

When spread on agricultural fields, the PFAS-containing biosolids can potentially contaminate crops and livestock. Research has shown that plants growing in soil that is repeatedly amended with PFAS-contaminated biosolids can impact all parts of the plant, including roots, shoots, and fruits. Consumption of crops that contain PFAS has the potential to cause adverse health effects in people and livestock. Furthermore, PFAS-containing biosolids can also possibly contaminate groundwater beneath the application site and/or surface water through surface runoff, causing a risk to the people and livestock that rely on local groundwater and/or surface water source as drinking water supply. Note that in other states (e.g., Maine), PFAS has been found in milk from dairy cows that consumed PFAS-containing crops and groundwater that are associated with land application of PFAS-contaminated biosolids.

A risk assessment is key to determining the potential hazard associated with human exposure to PFAS in biosolids. According to the PFAS Strategic Roadmap (EPA, 2021), the EPA will complete the risk assessment for PFOA and PFOS in biosolids by Winter 2024. The risk assessment will serve as the basis for determining whether regulation of PFOA and PFOS in biosolids is appropriate. If EPA determines that a regulation is appropriate, biosolids standards would be established to improve the protection of public health and wildlife health from exposure to biosolids that contain PFOA and PFOS. To date, regulations have not been promulgated for PFAS in biosolids at the federal level. At the state level, Maine has banned land application of biosolids due to the concerns around PFAS. Michigan conducted state-wide evaluation of the presence of PFAS in municipal wastewater and associated residuals (sludge/biosolids) across 42 municipal wastewater treatment plants and developed tiered requirements for PFOS in biosolids prior to land application.

In Colorado, CDPHE issued compulsory reporting and monitoring requirements for biosolids, with Broomfield being required to report once per quarter. The EPA anticipates finalizing the human health impacts assessment of biosolids in 2024, with regulations to follow in subsequent years. EPA Method 1633 continues to be the PFAS testing method for biosolids, although it will likely undergo at least two updates from 2023-2025. Most importantly, preparers will be required to provide information on source investigation and reductions if PFOS is detected to be 50 micrograms per kilogram (µg/kg) or greater (i.e., source investigation triggering level). These requirements will fall under Regulation 64.

In 2004, a survey by the North East Biosolids and Residuals Association showed that approximately 55 percent of wastewater sludge is recycled to soils as biosolids, 30 percent is landfilled, and the remaining 15 percent is incinerated. The feasibility and cost of each of these management options may be impacted by future PFAS regulations in biosolids. Studies have shown that in states where PFAS regulations have been implemented, biosolids management costs have increased by an average of 37 percent. The rapid cost increases have been attributed to reduced land application availability due to PFAS and the use of alternative high-cost disposal sites such as landfills. Meanwhile, cost impacts have been minimal at facilities that manage their own biosolids (e.g., via incineration), do not rely on biosolids beneficial reuse, and/or are located in areas without PFAS requirements or guidelines.

1.3.4.5 Other Solids Requirements

Regulation 64 does not include requirements for Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) in biosolids at this time; however, Senate Bill-245 was passed in Colorado that required CDPHE to develop new NORM and TENORM regulations even without the EPA having adopted such rules first, following a stakeholder process. The new rule, Part 20, was adopted in November 2020, became effective in January 2021, and has been enforceable since July 2022. For wastewater treatment plants, samples are required to be collected from bar screens, sediment and grit, and biosolids for testing concentrations of radium and its progeny (Radium-226, Radium-228, Lead-210, and Polonium-210), called TENORM.

For initial characterization sampling, most treatment plants only need to sample for Radium-226 and Radium-228. However, if a treatment plant receives industrial wastewater with known concentrations of Lead-210 or Polonium-210 that exceed the concentrations of radium, sampling of Lead-210 and Polonium-210 is also required. Sampling is needed at the end of a process, where the material is still under control of the generator, and where a sample is reasonably readily accessible. Furthermore, historical samples that have already been collected are acceptable if there has not been a substantial change in the raw material or treatment process. Other methods for characterization of residual TENORM may also be allowed if approved by the Radiation Program (e.g., calculate expected residual radium concentration using known raw water radium concentrations and knowledge of the treatment process).

The CDPHE has developed a spreadsheet (SW-846 calculator) that calculates the expected TENORM concentration of a material based on three or more random samples. The CDPHE recommends collecting six random samples from each material requiring characterization, sending three to a lab for evaluation, and running these three results through the spreadsheet. If the spreadsheet states that more samples are needed to characterize the material, the plant can then send the remaining three samples to a lab for evaluation. For lab analysis, methods must be chosen that have a minimum detection limit below 5 picocuries per gram (pCi/g). Additionally, gamma spectroscopy for measurement of Radium-226 will not work if the sample also likely contains uranium. If samples with more than 90 percent moisture are tested, the lab must not filter out any solids during analysis and must also report total dissolved solids (TDS) and TSS concentrations. The rule guidance contains recommended sampling methods and lessons learned.

Once the required material is characterized, it will fall in one of three categories for this regulation: exempt, registration required, or license required. Table 1.12 shows the concentrations of TENORM applicable for each category as well as the applicable regulation requirements. Per the CDPHE, it is expected that most treatment plants will be either exempt or require registration. If initial sampling shows a facility is exempt, no additional sampling is required unless there is a change to the treatment process or material treated. Furthermore, no application for exemption is needed. It is just recommended the treatment plant keep a record of the characterization data. If initial sampling shows a facility will require registration, at least one sample will be required annually. The facility can use samples taken for other purposes. If supported by data, the sampling frequency may be decreased over time.

1.3.5 Summary of Regulatory Drivers Assessment

Based on current monitoring and trends, some future regulatory requirements are expected while some are less certain. Permit renewal cycles previously were regular at a 5-year interval, but renewals have fallen behind and longer periods between permit renewals are occurring. Planning efforts should consider the following:

- Temperature limits within the next permit renewal cycle, with implementation sometime in the early 2030s. A significant reduction in winter effluent temperature will likely be required.
- Regulation 31 nutrient limits – likely set at the ultimate water quality standard – in the late 2030s.
- Unknown timing and requirements for PFAS, radionuclides, other metals and contaminants based on monitoring results and regulatory horizons.

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Table 1.12 Part 20 TENORM Regulation Requirements

TENORM Limit(1)	Characterization Category	Sampling Requirements	Requires Annual Registration and Following General Provisions(2)	Requires Staff Training(3)	Requires Spill and Release Protocols(4)	Requires Keeping Records(5)	Restricts Disposal or Transfer of Material(6)	Requires Material Containment	Restricts Service Provider Handling Material(7)	Requires Indoor Air Radon Monitoring and Dose Rate Survey(8)	Allows Reuse, Recycling, or Beneficial Use
< 5 pCi/g	Exempt	Initial characterization only	No	No	No	No	No	No	No	No	No
5-50 pCi/g	Registration Required	Initial characterization and at least one additional sample annually	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
50-500 pCi/g > 10% Solids, accepted through collection system from a water treatment plant, and > 10% of total volume received by the wastewater treatment plant	Registration Required	Initial characterization and at least one additional sample annually	Yes	Yes	Yes	Yes	Yes	Yes	Yes, for direct handling	No	Yes
> 500 pCi/g	License Required(9)	License Required(9)	License Required(9)	License Required(9)	Initial characterization and then license specific	Initial characterization and then license specific	License Specific	License Specific	License Specific	License Specific	License Specific

Notes:
(1) Dry weight concentration for each of the four TENORM chemicals (Ra-226, Ra-228, Pb-210, and Po-210) over background levels.
(2) Annual registration and general provision requirements are outlined in Section 20.5.1 and 20.5.2 of the regulation, respectively. These requirements include, but are not limited to, labeling registered material as radioactive, reporting material theft or loss, limiting maintenance to trained personnel, and minimizing contamination of the facility and environment.
(3) Training requirements are outlined in Section 20.5.3 of the regulation. These requirements include, but are not limited to, training individuals whose job includes exposure to registered material in the proper storage, transfer, and use of registered material. Such training shall occur within 90 days of employment and subsequently once every three years.
(4) Spill and Release requirements are outlined in Section 20.5.4 of the regulation. These requirements include, but are not limited to containing all spills and releases of registered material. CDPHE notification is required if 10 µCi or more of registered material is released. CDPHE may require remediation of such spills.
(5) Records requirements are outlined in Section 20.10 of the regulation. These requirements include, but are not limited to, recording receipt, transfer, and disposal of registered material; recording employee training status; and recording radiological characterization information.
(6) Registered material must be disposed of at a commercial solid waste facility registered with the CDPHE, at a facility authorized to receive such material, to a sanitary sewer for treatment at a domestic wastewater treatment facility, or to state waters in accordance with the Water Quality Control Act. See Sections 20.6.2.A.2 and 20.6.2.B.4 for more details.
(7) Direct handling must be performed by individuals with a specific radioactive materials license or equivalent licensing document issued by the CDPHE, NRC, or any Agreement State. See Sections 20.6.2.A.4 and 20.6.2.B.2 for more details.
(8) Indoor air radon monitoring is required if materials contain > 50 pCi/g of Ra-226 and are located in an occupied indoor workspace. Monitoring must demonstrate that average indoor radon levels are not in excess of the EPA's 4 pCi/L action level. Additionally, if registered materials contain > 50 pCi/g of any TENORM compound, radiation dose rate surveys must be conducted and show that radiation dose rates do not exceed 2 millirem/hr at 30 centimeters from the radiation source. Furthermore, these surveys must show that radiation dose rates do not exceed 11 microrem/hr above background beyond the facility boundary. Additional restrictions are required if the radiation dose rate surveys show that radiation dose rates exceed 50 microrem/hr at 30 centimeters excluding background. See Sections 20.6.2.A.4.c and 20.6.2.A.d for more details.
(9) To apply for a specific license, see the requirements in Section 20.13 of the regulation.

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1.4 Greenhouse Gas Emissions Summary

To provide Broomfield a means to quantify the GHG emissions associated with the annual operations of the BWRF and a summary of the baseline emissions inventory, Carollo developed a GHG inventory tool. Quantifying GHG emissions will allow Broomfield to plan the most cost-effective means of managing and reducing GHG emissions (or increasing offsets) and adapt to regulatory and operational changes over time. Plant data from 2021 was used to establish a baseline for GHG emissions as it was the most recent complete year of data available.

A GHG inventory is intended to estimate GHG emissions emitted by a person, organization, or process over a period of time. Six GHGs have been prioritized for GHG inventory purposes, based on the capacity of each gas to absorb and reradiate heat, and thus contribute to climate change. These GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Of these, CO_2, CH_4, and N_2O are considered relevant for wastewater treatment emissions and are the focus of this inventory. To account for the variation in the ability for each gas to absorb and reradiate heat, Global Warming Potentials (GWP) are used to relate gases to CO_2 on a mass basis (e.g., carbon dioxide equivalent [CO_2e]).

The *Greenhouse Gas Protocol – A Corporate Accounting and Reporting Standard*, developed by the Greenhouse Gas Protocol Initiative, provides the framework for the inventory which ensures relevance, completeness, consistency, transparency, and accuracy of the results. Carollo created the inventory in alignment with the GHG Protocol, developed by the World Resources Institute and the World Business Council for Sustainable Development (WRI/WBCSD), and in compliance with the federal GHG Mandatory Reporting Rule. The WRI/WBCSD developed the Greenhouse Gas Protocol Initiative to provide private and public entities around the world with a credible means to calculate and manage GHG emissions. The Protocol serves as an accounting framework for almost all GHG standards and programs in the world, including the Organization of International Standards, the European Union Emissions Trading Scheme, and The Climate Registry.

1.4.1 GHG Regulations

The EPA gained the authority to regulate GHG emissions through the Clean Air Act in 2007. By 2009, the Mandatory GHG Reporting Rule was adopted, requiring stationary combustion sources emitting 25,000 metric tons (mt) of CO_2e per year or more to report annual GHG emissions. GHG emissions are typically reported as tons of CO_2e, which is calculated by multiplying the mass of each GHG emitted by its associated GWP. GWP is a mass-based measure expressing how much a given GHG is estimated to contribute to global warming relative to CO_2. GWPs and CO_2e are further discussed below.

The Mandatory GHG Reporting Rule was the EPA's first step, before developing future reduction requirements for GHGs in support of international agreements. The most recent of these is the Paris Agreement ratified by the U.S. on August 29, 2016. The Paris Agreement requires all signed parties to achieve "nationally determined contributions," and that all parties report on their GHG emissions and implementation efforts.

While centralized domestic wastewater treatment systems were explicitly excluded from the EPA reporting regulation, they often have stationary combustion sources, which are required to report emissions if the stated emissions threshold is met. Therefore, it is important for wastewater treatment facilities to monitor GHG emissions, to ensure emissions remain below 25,000 mt of CO_2e to avoid reporting (and eventual reduction) requirements.

In addition to national regulations, applicable state and local regulations, initiatives, and/or guidelines have been developed by various agencies. One example is the Colorado Climate Plan, formed in 2015. The Plan aims to improve GHG emissions statewide and aligns with Colorado House Bill 13-1293, passed in 2013, which may impact wastewater treatment facilities in the future.

1.4.2 System Boundary

Establishing the system boundary is a necessary first step to define life cycle stages (e.g., construction, operations, etc.), unit processes, and time frame (e.g., present or future year) for building a GHG inventory. This section provides an overview of the system boundary and the types of information used as a basis for the GHG emissions estimates.

The system boundary for the BWRF establishes the premise for estimating GHG emissions and includes only operations necessary for the proper treatment of wastewater and sewage sludge. Emissions are estimated from the time the wastewater enters the plant to the point the effluent is discharged to Big Dry Creek and GWR, the transportation of biosolids to A1 Organics for composting, and the transportation of grit/screenings to the landfill. Emissions from fleet vehicles are not included in this inventory.

The timeline evaluated is defined as the 2021 annual operations of the WRF. The liquids system processes include screening and grit removal, influent pumping, primary clarification, biological nutrient removal (BNR), secondary clarification, ultraviolet (UV) disinfection, and treatment of reclaimed water. The solids system processes include truck transport for grit and screenings disposal, DAF thickening, anaerobic digestion, centrifuge dewatering, and truck transport for composting. Other processes include building electricity and natural gas use, photovoltaic (PV) electricity production through solar panels, and transport associated with chemical consumption.

Offsets from land application of biosolids following composting at A1 Organics are not included within the system boundary at this time. If Class B biosolids are generated onsite in the future and sent to land application, offsets associated with land application (carbon sequestration and avoided fertilizer use) can be added to the scope of this inventory.

1.4.3 Methods

The process of estimating GHG emissions is important to produce results that are trusted and verifiable. The process requires use of estimating protocols and GWP, identifying and categorizing emission sources, and selecting the appropriate emission factors. Carollo has developed a GHG emissions estimating and reporting tool specifically for the BWRF based on methods aligned with the GHG Protocol Initiative, an accounting protocol developed by the WRI/WBCSD. This protocol serves as an accounting framework for almost all GHG standards and programs in the world – from the Organization of International Standards to The Climate Registry General Reporting Protocol to the EPA's mandatory GHG reporting program. This section provides summaries of key protocols referenced in the tool, the emissions sources organized by scope, and how emission factors and GWPs are used to estimate emissions by source.

1.4.3.1 Protocols

In order to estimate GHG emissions from wastewater treatment facility sources, there are a number of estimating protocols that (in combination) serve as the basis for a complete inventory of the BWRF. These protocols include:

1. 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories.
2. EPA's Mandatory Greenhouse Gas Reporting Rule (40 Code of Federal Regulations Part 98, 40 CFR Part 98).
3. Water Environment Research Foundation (WERF).

IPCC

Established in 1988, the IPCC serves as an international organization dedicated to climate change research. The IPCC is responsible for providing up to date information regarding the risks, impacts, and assessments of climate change. Additionally, the IPCC developed the updated *2006 IPCC Guidelines for National Greenhouse Gas Inventories,* which were further refined in 2019 to serve as a consistent framework for all nations to report. These guidelines are comprised of five volumes: 1) General Guidance and Reporting; 2) Energy; 3) Industrial Processes and Product Use; 4) Agriculture, Forestry, and Other Land Use; and 5) Waste. Volume 5 contains estimating approaches relevant for wastewater treatment operations and was used as the basis for many of the WRF's inventory calculations.

EPA

The EPA established a reporting threshold of 25,000 mt of fossil fuel related CO_2e emissions per year through the Mandatory GHG Reporting Rule. This rule includes methods used to identify and estimate GHG emissions, primarily based on methodologies established by the IPCC.

The calculations and emission factors that must be used to determine GHG emissions for regulatory purposes are provided in 40 CFR 98.33. Publicly Owned Treatment Works (POTW) are required to report direct emissions associated with stationary combustion units, fueled by both anthropogenic and biogenic fuel sources (e.g., natural gas and biogas, respectively). As an incentive to capture and use biogas for electricity and heating needs, although CH_4, N_2O, and CO_2 from biogas are included in the reporting requirements, CO_2 from biogas is considered biogenic and is exempt from reduction requirements at this time.

Due to the direct application of mandatory reporting requirements for the BWRF, the EPA protocol was used for facility-level inventory calculations whenever applicable, including population-based nitrous oxide emissions associated with BNR resulting from nitrification and denitrification.

WERF

WERF, a research branch of WEF, is dedicated to conducting climate change research as it applies to wastewater treatment. Research also involves evaluating and developing technologies to adapt to the potential impacts of climate change.

WERF established research-based emission factors associated with BNR in 2010. Results showed that BNR emissions are highly variable and dependent on many site-specific conditions (e.g., temperature, humidity, influent quality, etc.). While WERF research has been conducted to determine emission factors that are more accurate than the EPA population-based emission factors, EPA emissions factors were used for this inventory to align with the national emissions inventory used for reporting purposes.

1.4.3.2 Emissions Sources by Scope

Determining the sources of emissions and offsets within the system boundary served as a fundamental step in the development of the inventory. Emissions are typically categorized as Scope 1, Scope 2, or Scope 3, as a standard and for comparison across other inventories. Below are summaries of each Scope category as they relate to the Broomfield's operations at the WRF.

Scope 1

Scope 1 includes direct anthropogenic (fossil fuel based) and biogenic GHG emissions related to on-site combustion and treatment processes within the system boundary. Scope 1 emission sources within the system boundary identified at the WRF include:

- Emissions due to natural gas combustion.
- Emissions due to biogas combustion, including biogenic CO_2, CH_4, and N_2O.
- Process emissions due to nutrient removal processes; includes nitrification and denitrification processes.
- Process emissions due to remaining nitrogen concentrations in the effluent discharge.

For this inventory, at Broomfield's direction, fleet vehicles were not included in the system boundary.

At this time, mandatory GHG emissions reporting is limited to Scope 1 emissions above 25,000 mt of CO_2e per year – specifically, natural gas and biogas combustion (CH_4 and N_2O only).

Scope 2

Scope 2 encompasses indirect anthropogenic emissions related to the consumption of purchased electricity, steam, heating, or cooling. These emissions are a result of the treatment plant operations but occur at a source that is not owned or operated by the WRF. Emissions identified as Scope 2 within the system boundary include purchased electricity for wastewater treatment and water reclamation processes.

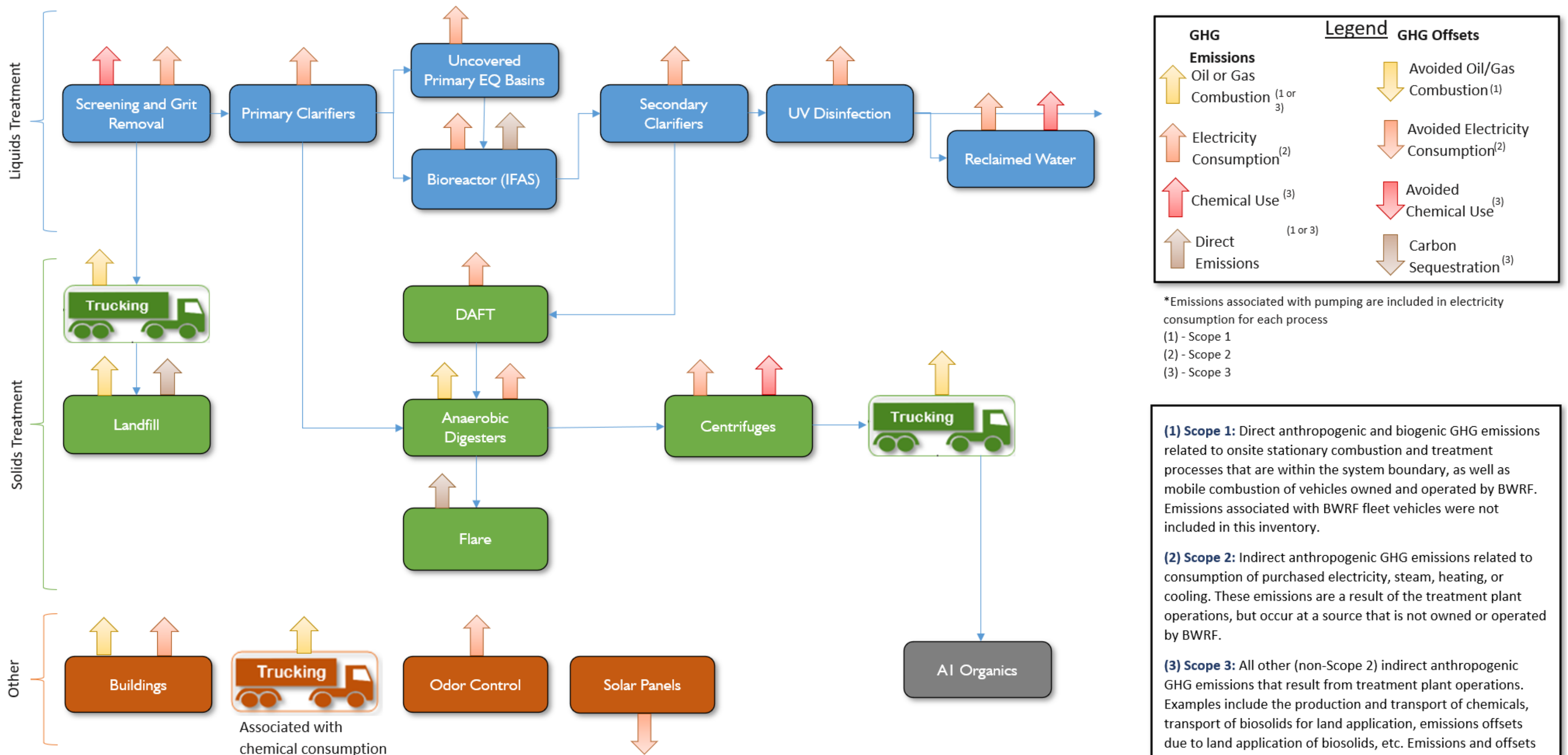
Scope 3

All other (non-Scope 2) indirect anthropogenic GHG emissions that result from treatment plant operations are considered Scope 3 emissions. Examples include the production and the transport of chemicals. Scope 3 emissions within the system boundary identified at the WRF include:

- Natural gas production.
- Chemical production; including sodium hypochlorite, ferric chloride, and emulsion polymer.
- Chemical transport; including truck and freight.
- Biosolids transport to A1 Organics.
- Solids (grit/screenings) transport to landfill.

Offsets were also identified within Scope 3. Offsets at the WRF include avoided purchased electricity through onsite photovoltaic electricity production. Avoided purchased electricity through biogas compression and reuse in the boilers for digester heating would also be included as an offset; however, the system at the WRF is currently not used. Offsets associated with land application of biosolids are not currently included in the scope of this inventory. If higher quality biosolids are produced from the facility in the future, this could be another source of offsets from the WRF.

An illustration of emissions and offsets within the system boundary is shown in Figure 1.32.



*Emissions associated with pumping are included in electricity consumption for each process
(1) - Scope 1
(2) - Scope 2
(3) - Scope 3

(1) Scope 1: Direct anthropogenic and biogenic GHG emissions related to onsite stationary combustion and treatment processes that are within the system boundary, as well as mobile combustion of vehicles owned and operated by BWRF. Emissions associated with BWRF fleet vehicles were not included in this inventory.

(2) Scope 2: Indirect anthropogenic GHG emissions related to consumption of purchased electricity, steam, heating, or cooling. These emissions are a result of the treatment plant operations, but occur at a source that is not owned or operated by BWRF.

(3) Scope 3: All other (non-Scope 2) indirect anthropogenic GHG emissions that result from treatment plant operations. Examples include the production and transport of chemicals, transport of biosolids for land application, emissions offsets due to land application of biosolids, etc. Emissions and offsets due to processing and handling of biosolids by A1 Organics were not included in this inventory.

Figure 1.32 Emissions and Offsets within the System Boundary

1.4.4 Emissions Factors and Global Warming Potentials

Once the emission sources have been identified, established emission factors are selected for each source to relate GHG emissions generated amongst various processes. Emission factors represent the amount of CO_2, CH_4, or N_2O released per unit energy or fuel consumed. A summary of the emission factors used for the inventory calculations is provided in Table 1.13.

Table 1.13 Emissions Factors Used to Calculate GHG Emissions at BWRF

Emission Source	CO_2	CH_4	N_2O	Energy or Petroleum-Based Factor
Chemical Production				
Ferric Chloride	-	-	-	0.05 kWh/lb[1]
MicroC® 2000	-	-	-	9 Btu/lb[2]
Emulsion Polymer	4.08 kg CO_2e/lb[3]	-	-	-
Sodium Hypochlorite	-	-	-	2.5 kWh/lb[4]
Biological Treatment Process				
Effluent Discharge Emissions	-	0.021 kg CH_4/kg BOD[5]	0.005 kg N_2O-N/kg sewage-N produced[5]	-
Nitrification/ Denitrification Process Emissions			0.0050 g N emitted as N_2O/g influent TKN[5]	-
Biogas and Biosolids Production				
Biogas Combustion	52.07 kg CO_2/MMBtu[6]	3.20E-03 kg CH_4/MMBtu[6]	6.30E-04 kg N_2O/MMBtu[6]	-
Biogas Heat Content				500 Btu/scf[7]
Biosolids Carbon Sequestration	0.25 mt CO_2e/ dry mt[8]	-	-	-
Fertilizer Offset	0.23 mt CO_2e/ dry mt[8]	-	-	-
Fossil Fuel Consumption				
Xcel (Colorado) Electricity Production	1,133 lb CO_2/MWh[9]	0.105 lb CH_4/ MWh[9]	0.015 lb N_2O/ MWh[9]	-
Natural Gas Production	3.631E-05 kg CO_2/cf[5]	6.516E-05 kg CH_4/cf[5]	5.947E-10 kg N_2O/cf[5]	-
Natural Gas Consumption	53.06 kg CO_2/MMBtu[6]	0.001 kg CH_4/MMBtu[6]	0.0001 kg N_2O/MMBtu[6]	
Colorado Natural Gas Heat Content	-	-	-	1,060 Btu/scf[10]
Combination Truck Fuel Efficiency	-	-	-	5.92 mi/gal[11]
Diesel Consumption	10.21 kg CO_2/gallon[6]	0.0051 g CH_4/mile[6]	0.048 g N_2O/mile[6]	-

Emission Source	CO_2	CH_4	N_2O	Energy or Petroleum-Based Factor
Freight Train Fuel Efficiency	-	-	-	473 ton-mi/gal(12)
Gasoline Consumption for Light Duty Trucks 2005+	8.7775 kg CO_2/ gallon(13)	0.0163 g CH_4/mi(14)	0.0066 g N_2O/mi(14)	-

Notes:
(1) Owen, William F. January 1982. "Energy in Wastewater Treatment."
(2) Correspondence with Sam Ledwell, Director of Technical Development – Environmental Operating Solutions. 1/15/09. Assumed to be the same as MicroC®.
(3) Carnegie Mellon Green Design Institute. Accessed: September 2016. EIO-LCA Tool. www.eiolca.net.
(4) Ernst, Worrell. April 2000. "Energy Use and Energy Intensity of the U.S. Chemical Industry."
(5) IPCC. May 2019. "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories."
(6) "40 CFR 98.33" and Subpart C Table C-1. July 2021.
(7) WRF does not currently test digester gas. Industry values are typically 500-600. Assumed lower end of the range due to incomplete digestion.
(8) Brown et al. September 2004. BioCycle. "Building Carbon Credits with Biosolids Recycling."
(9) Xcel Energy. 2019. "Carbon Dioxide (CO_2) Emissions Intensities."
(10) U.S. Energy Information Administration. October 2016. "2015 Colorado Heat Content of Natural Gas Deliveries to Consumers." www.eia.gov.
(11) Climate Leaders Greenhouse Gas inventory Protocol Core Module Guidance. May 2008. "Fuel Economy Values by Vehicle Type."
(12) Association of American Railroads. April 2011. "The Environmental Benefits of Moving Freight by Rail." www.aar.org.
(13) The Climate Registry. 2011. "General Reporting Protocol for the Voluntary Reporting Program."
(14) EPA. April 2016. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014."

Btu	British thermal units	lb	pound
cf	cubic foot	MMBtu	million British thermal units
kWh	kilowatt-hour	scf	standard cubic foot

The Kyoto Protocol, a voluntary international agreement between countries to reduce GHG emissions, established six priority GHGs to evaluate when performing calculations for inventory purposes. CO_2, CH_4, and N_2O are the GHGs considered relevant to wastewater treatment plant related emissions. To account for the variation in the ability for each gas to absorb and reradiate heat, GWPs are used to relate gases to CO_2 on a mass basis (e.g., CO_2e). An assumption of the time horizon must be made to generate meaningful emissions estimates when selecting GWPs. The typical time horizon selected is 100 years, which is what was used for this inventory. Based on this time horizon, CH_4 is estimated to have 25 times the capacity to absorb and reradiate heat relative to CO_2 while N_2O is estimated to have 298 times the capacity. A summary of GWPs applicable to POTWs as determined by the IPCC in the Fourth Assessment Report is provided in Table 1.14.

Table 1.14 GHG 100-Year Global Warming Potentials(1)

Greenhouse Gas	Formula	Atmospheric Lifetime (years)	GWP
Carbon Dioxide	CO_2	50-200	1
Methane	CH_4	12	25
Nitrous Oxide	N_2O	114	298

Notes:
(1) Source: Intergovernmental Panel on Climate Change, Fourth Assessment Report, 2007.

The Fourth Assessment Report GWPs are used today by international convention and the U.S. to maintain the value of the carbon dioxide "currency," and are used in this inventory to maintain consistency with international practice.

1.4.5 Data Sources

Data used to develop the inventory was provided by Broomfield to establish the baseline GHG emissions for 2021 operations and included the following:

- Broomfield Operations daily readings.
- BWRF Record Drawings.
- Xcel electrical and natural gas use.
- Correspondence with BWRF staff.

1.4.6 BWRF Emissions Estimates and summary table

The total direct and indirect GHG emissions generated by the existing BWRF, excluding biogenic CO_2, are estimated to be approximately 7,154 mt CO_2e annually. Most emissions are due to indirect sources, included in Scopes 2 and 3. The largest source of indirect emissions, 4,111 mt CO_2e, is a result of purchased electricity. The next largest source of indirect emissions is due to chemical production at 852 mt CO_2e per year. The largest source of direct emissions is due to process emissions at 1,150 mt of CO_2e. GHG offsets include avoided purchased electricity from PV electricity generation for a total of -73 mt CO_2e. Refer to Table 1.14 and Figure 1.31 for a breakdown of GHG emissions by category and source.

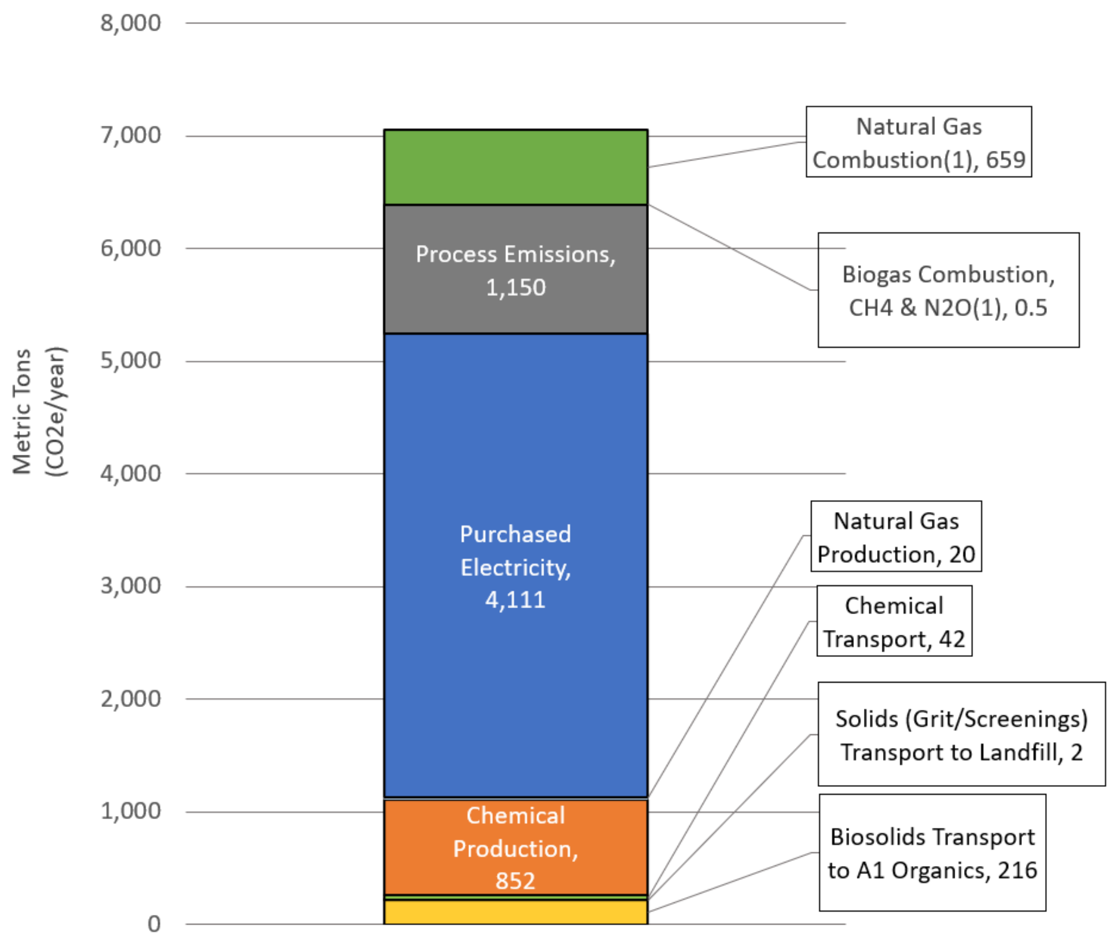
Currently the EPA reporting threshold is 25,000 mt of CO_2e per year. Regulated emissions from BWRF account for a total of 760.5 mt of CO_2e per year, well below the EPA threshold, meaning that BWRF is not required to report GHG emissions at this time.

Table 1.15 BWRF 2021 Greenhouse Gas Emissions and Offsets Estimates

Source	Emission (metric tons CO_2e/year)	Emission (%)
EMISSIONS		
Scope 1	1,911	(7)
Scope 1 (Without Biogenic CO_2)	**1,810**	**24.7**
Natural Gas Combustion(1)(6)	659	9.3
Biogas Combustion, Biogenic CO_2(7)	101	(7)
Biogas Combustion, CH_4 & N_2O(1)(6)	0.5	0.0
Process Emissions(2)	1,150	16.3
Scope 2 – Purchased Electricity(5)	**4,111**	**58.3**
Scope 3	**1132**	**16.1**
Natural Gas Production(2)	20	0.28
Chemical Production(5)	852	12.1
Chemical Transport(3)	42	0.02
Grit Screenings to Landfill(3)	2	0.0
Biosolids Transport(3)	217	3.1

Source	Emission (metric tons CO_2e/year)	Emission (%)
Offsets	**-73**	
PV Electricity Generation[5]	-73	
TOTAL EMISSIONS SUMMARY		
Scopes 1, 2, & 3 (Emissions) Total	7,154	
Scopes 1, 2, & 3 (Emissions Without Biogenic CO_2) Total	7,052	
Offsets Total	-73	

Notes:
(1) 40 CFR 98.33 and Subpart C Table C-1. July 2021.
(2) IPCC. May 2019. "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories."
(3) EPA. 2016. "Climate Leaders Mobile Sources."
(4) Brown et al. September 2004. BioCycle. "Building Carbon Credits with Biosolids Recycling."
(5) The Climate Registry. May 2019. "General Reporting Protocol."
(6) Applicable to EPA's Mandatory GHG Emissions Reporting Rule.
(7) Emissions associated with biogenic CO_2 combustion are reported to EPA but are not the focus of emissions reductions and are therefore not included in percentage calculations.



Notes:
(1) Emission source that is included in federal regulations. Applicability of regulations must be evaluated.
(2) Offset from PV (electricity generation) is accounted for as a reduction in purchased electricity.

Figure 1.33 Emissions and Offsets by Category

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Chapter 2

FACILITY ASSESSMENT

2.1 Introduction

A facility assessment of each major unit process at the BWRF was conducted to document age, initial summary of facility condition, and operational challenges. The intent of this assessment is a general narrative of overall facility condition to inform big picture decisions for the future planning of the BWRF, rather than the minutiae of individual equipment replacement. This assessment is not a detailed component condition assessment.

For each unit process, this chapter includes a short narrative introduction, tabular summary, and notes on future needs. The following unit process areas were evaluated:

- Preliminary Treatment.
- Primary Treatment.
- Secondary Treatment.
- Tertiary Filtration and Disinfection.
- Odor Control.
- Solids Thickening.
- Digestion.
- Dewatering.
- Electrical Infrastructure.
- Instrumentation and Controls (I&C) Systems.

Notes and photos from the facility assessment conducted on October 3, 2022, are summarized by discipline in the appendices. Process discipline assessment is summarized in Appendix 2A. Mechanical discipline assessment is summarized in Appendix 2B. Structural discipline assessment is summarized in Appendix 2C. Electrical discipline assessment is summarized in Appendix 2D. Instrumentation and controls discipline assessment is summarized in Appendix 2E. A general summary of the findings is shown in Figure 2.1.

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Facility Assessment Site Plan

1 PRIMARY TREATMENT
- Replace flow equalization basin and pumping, and primary sludge pumping.
- Evaluate primary clarifier concrete and mechanism condition to consider future steps.

2 PRELIMINARY TREATMENT
- Upgrade HVAC and odor control air flows.
- Plan rebuild of influent pumps.
- Consider influent flow measurement improvements, address metals corrosion in girt room, and evaluate hydraulic capacity and limitations in channels for peak flow.

3 SITE ELECTRICAL
- Recommend a full plant one-line diagram.
- Update arc-flash study and provide equipment labeling.
- Replace switchboard in West Generator Building.
- Replace site lighting.

4 SECONDARY TREATMENT
- Replace South Train capacity with new treatment train.
- Replace Middle Train IR, RAS, and WAS pumps and associated electrical, and IFAS system.
- Replace old North Train blowers
- Replace secondary clarifier mechanisms for SC 3 and 4.

5 I&C SYSTEMS
- Improve aeration/DO control.
- Plan PLC and instrumentation upgrades in parallel with project work.

6 SOLIDS THICKENING
- DAF redundancy for WAS thickening.

7 ODOR CONTROL
- Conduct odor control study.
- Construct new odor control system at new EQ facility and combine nearby existing foul air flows.
- Replace odor control fans, associated ductwork, and metal building.

8 DIGESTION
- Construct new digestion complex, including digesters, dewatering feed pumps, and pre-dewatering sludge storage.
- Consider capacity and desire to achieve Class B biosolids and beneficial reuse of biogas.

9 TERTIARY TREATMENT
- Replace filter backwash pumps and HVAC in chemical rooms.
- Evaluate UV disinfection hydraulics and update, if necessary.
- Consider logical approach to reuse filtration system expansion.
- Add jockey reuse pump in fourth bay and upgrade reuse pump VFDs.

10 DEWATERING
- Replace conveyors.
- Increase centrate storage/consider treatment.
- Replace centrifuges with larger capacity units or 3 centrifuges if mechanical connections and access can be defined.
- Plan for sludge storage volume and replace dewatering feed pumps.

Figure 2.1 Summary of Condition Assessment Findings

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2.2 Preliminary Treatment

Preliminary treatment includes influent screening, pumping, and grit removal. These facilities were predominantly constructed in the 2007 Phase 2 Project, although components of the Influent Pumping Station were constructed in 2001. While relatively new, there are some concerns about air movement and corrosion in a few areas.

Table 2.1 Preliminary Treatment Condition Summary

Item	Description
Initial Construction	2007 Phase 2 Project, with components of the Influent Pumping Station constructed in the 2001 Phase 1 Project.
Modifications History	No significant modifications.
Components	Influent step screens, dry-pit influent pumps, influent flow meters, Headcell grit removal, grit pumping.
Mechanical Condition	Limited air movement noted, concerns with heating, ventilation, and air conditioning (HVAC) and odor control maintaining National Fire Protection Association (NFPA) 820 classification levels. Air diffuser for post-screenings channel does not work. Freeboard concerns at peak flow. Influent pumps need planned rebuild sequence. Is grit causing excess wear in influent pumps?
Structural Condition	Grit basins coating has failed.
Electrical Condition	Need to replace lighting.
Instrumentation Condition	Inadequate flow meter lay length.
Operations Challenges	Generally good equipment performance.
Future Needs	Confirm hydraulic capacity for peak flows.

2.2.1 Preliminary Treatment – Recommended Improvements

Recommended improvements include:

- Upgrade HVAC and odor control air flows.
- Plan rebuild of influent pumps.
- Consider influent flow measurement improvements.
- Address metals corrosion in the Grit Room.
- Evaluate hydraulic capacity and limitations in channels for peak flow.

2.3 Primary Treatment

Primary treatment includes primary clarifiers (PC), primary sludge pumping (located within the Old Headworks Building), flow equalization (EQ), and EQ pumping (located in the EQ Pump Building). The facilities where this equipment is located have had iterative construction and modifications. The three primary clarifiers are covered, which is good for odor control but limits the ability to observe condition and can exacerbate corrosion if ventilation is reduced. Flow EQ is in an open basin at the south end of the site away from other primary treatment components.

Carbon addition storage and pumping to the unaerated zones is in the Old Headworks Building, and that work is currently in progress with anticipated completion in 2023.

Table 2.2 Primary Treatment Condition Summary

Item	Description
Initial Construction	1986 Old Headworks Building, flow EQ basin and pump station, PC 1 and PC 2. PC 3 added in Phase 1 Project in 2001.
Modifications History	Replaced PC 1 and PC 2 center drives and added new clarifier covers in 2016. Carbon addition tanks and pumps added in 2022, replacement of Old Headworks Building HVAC. Flow EQ basin and pumps at end of life.
Components	PCs 1-3, primary sludge pumps, primary scum pumps, primary odor fans, new carbon addition systems.
Mechanical Condition	Primary clarifier mechanisms not observed, but PC 1 and PC 2 likely nearing end of life. PC 1 and PC 2 were inspected prior to the new covers and some corrosion was noted, leading to the replacement of scum box and piping components. Primary sludge pumps at end of life. Flow EQ Pump Station at end of life. Flow EQ basin coarse bubble aeration nearing end of life. Odor control blowers and metal building at end of life. New HVAC in Old Headworks Building.
Structural Condition	Need to evaluate primary clarifier concrete condition when out of service. Primary clarifier covers in good condition. Metal Odor Control Fan Building is at end of life. Need to consider egress in below grade Primary Sludge Pump Station in retrofit; sump cover is corroded.
Electrical Condition	Motor control centers (MCC) upgraded in 2022. Some older exterior lights at the primary clarifiers should be replaced.
Instrumentation Condition	Older instruments at primary sludge pumping and EQ are at end of life. Programmable logic controller (PLC) in Old Headworks Building has several recent upgrades.
Operations Challenges	Limitations on maximum primary sludge thickness based on pump operation. Odor concerns from flow EQ basin.
Future Needs	Evaluate primary sludge thickness and pumping capacity range based on process needs. Evaluate primary clarifier mechanical and concrete condition when out of service. Evaluate influent loading and process performance and determine whether a fourth primary clarifier is necessary and at what timing.

2.3.1 Primary Treatment – Recommended Improvements

Recommended improvements include:

- Replace flow EQ basin and pumping.
- Replace primary sludge pumping.
- Evaluate primary clarifier concrete and mechanism condition.
- Schedule future replacement of primary clarifier mechanisms.

2.4 Secondary Treatment

Secondary treatment includes the south, middle, and north trains of unaerated and aerated basins and secondary clarifiers. These are supported with aeration blowers and associated internal recycle (IR), return activated sludge (RAS), and waste activated sludge (WAS) pumps.

The aerated basins utilize an integrated fixed film activated sludge (IFAS) process. The south train is the oldest, having been modified and repurposed twice. The middle train is second oldest, being repurposed to IFAS along with the south train in 2001. The north train was purpose-built as IFAS in 2007. Due to time constraints, the facility assessment did not directly observe the north train.

The south and middle trains share a Mechanical Building for aeration blowers and RAS/WAS pumping, as well as a separate repurposed building for IR pumps. The north train has a separate Mechanical Building for these components, with the intent of expandability for a future fourth train envisioned as part of "Phase 3". Aeration control to maintain dissolved oxygen setpoints in the second aerated zone of each basin is currently being assessed for process optimization opportunity.

Table 2.3 Secondary Treatment Condition Summary

Item	Description
Initial Construction	South train constructed circa 1974. Middle train constructed circa 1986. North train constructed in 2007 Phase 2 Project.
Modifications History	South and middle trains have several modifications, most recently with conversion to IFAS in 2001 Phase 1 project. Blowers replaced in 2016 in all trains.
Components	North, middle, and south unaerated and aerated basins, IR pumps, blowers, SCs 1-6, RAS and WAS pumping. Variety of mechanical mixers installed in unaerated zones.
Mechanical Condition	South train nearing end of useful life; has not normally been operated. Middle Train pumps have limited access.
Structural Condition	South train was out of service, easily observed, and are at end of structural life. Concrete is in poor condition, metals show corrosion. Middle train concrete was generally not visible while in service. Unaerated zone concrete shows temperature and shrinkage cracks.
Electrical Condition	Exterior electrical in the middle and south trains shows corrosion. Exterior lighting should be replaced. Middle/south aeration electrical equipment and MCCs are older, showing age, and have access challenges. Floor transformers and older variable frequency drives (VFD) are in poor condition and should be planned for replacement.
Instrumentation Condition	Older instrumentation such as level sensors and pH probes are due for replacement. Upgrade PLC with associated process work in middle/south trains. Aeration control programming is working to original intent but requires modification for process optimization for new more stringent regulatory requirements.
Operations Challenges	South train challenging to operate and has been normally out of service. Side water depth in Secondary Clarifier (SC) 1 and SC 2 only 7 feet. Limited maintenance access to middle/south train IR pumps, and no cross-train flexibility in operation. Middle train has freeboard issues in IFAS basins. Future modifications should evaluate flow split control.
Future Needs	Will need capacity from third train in future. Consider construction of fourth train marked in concepts as Phase 3 and abandoning south train in lieu of costly modifications to make more operable, given age of infrastructure. Consider IFAS media fill fractionation.

2.4.1 Secondary Treatment – Recommended Improvements

Recommended improvements include:

- Plan for replacement of south train capacity elsewhere in facility.
- Upgrade aeration control.
- Replace middle train IR, RAS, and WAS pumps in existing building, along with corresponding electrical improvements.
- Plan for replacement of middle train IFAS systems, considering freeboard.
- Upgrade north train redundant older blowers to match newer turbo blowers, considering treatment capacity approach.
- Replace SC 3 and SC 4 mechanisms.
- Replace MCC-EF1 and MCC-EF2 in the middle/south train Electrical Room.

2.5 Tertiary Filtration and Disinfection

Tertiary filtration and disinfection consist of reclaimed/reuse filtration, UV disinfection, reuse pumping, and chemical addition facilities. These consist of several standalone buildings on the east side of the facility and were predominantly constructed in the 2001 Phase 1 Project and have a few subsequent modifications.

Table 2.4 Tertiary Filtration and Disinfection Condition Summary

Item	Description
Initial Construction	2001 Phase 1 Project.
Modifications History	UV system replaced in 2021, limited modifications to other facilities noted.
Components	Reclaimed water filters, backwash pumps, reuse pumps, ultraviolet disinfection, flow splits, Ferric and Chlorine Chemical Buildings.
Mechanical Condition	Corrosion noted on metal components in Ferric Room and Hypochlorite Room. Ventilation in Chemical Rooms seems limited/insufficient. Reuse Pump Station has hot electrical loads and should have air conditioning.
Structural Condition	Recommend coating UV bridge crane and replacing cage ladders. Recoat steel roofs. Recommend recaulking exterior block at Reuse Pump Station – in poor condition. Replace corroded anchors in Hypochlorite Building. Mild aluminum corrosion in Filtration Building, other metals appear good.
Electrical Condition	MCCs in fair condition. Reuse Pump Station electrical equipment in fair condition but note the need for cooling to extend life of large VFDs. Recommend replacement of emergency lighting.
Instrumentation Condition	Panels and instrument displays in corrosive environments are showing corrosion. Cla-Val controls could have newer monitoring and control approach.
Operations Challenges	Reuse pumping could add a jockey pump to cover desired flow ranges. Ferric fill station has a lot of spills and leaks. Staff note concerns with hydraulics in UV system at higher flows. At time of observation, all UV channels were in service at normal flows.
Future Needs	Limited access to Chemical Rooms may affect ability to replace tanks in future. Expansion of reuse will require site footprint for filters and pumping.

2.5.1 Tertiary Filtration and Disinfection – Recommended Improvements

Recommended improvements include:

- Consider logical approach to reuse system expansion.
- Plan for replacement of filter backwash pumps.
- Jockey reuse pump in fourth pump bay.
- Upgrade reuse pump VFDs.
- Evaluate UV disinfection finger weir control hydraulics, and update if necessary.
- Evaluate and upgrade HVAC in Chemical Rooms.

2.6 Odor Control

Odor control at the BWRF consists of a treatment biofilter in the center of the facility, with five sets of odor control fans. Odor fans are located at the Old Headworks Building, Screenings Room, Grit Removal Building, unaerated portions of the aeration basins in the middle and south trains, and waste sludge pumping station that handles the foul air from the Solids Processing Building and sludge holding tanks. These facilities were predominantly constructed in 2001, with modifications in 2007. A prior biofilter from 1998 had been located east of PC 1 but was demolished for subsequent secondary process expansion and flows from the primary clarifiers and Old Headworks were routed to the 2001 biofilter.

In addition, ferric chloride is added upstream of the BWRF treatment processes to mitigate odors.

Table 2.5 Odor Control Condition Summary

Item	Description
Initial Construction	Most odor control equipment and fans were constructed in 2001, with some additions in 2007.
Modifications History	Minor modifications in 2007 included replacement of the top layer of odor biofiltration media.
Components	Odor fans, ductwork, and biofilter.
Mechanical Condition	Observations indicate that air flows and ventilation are lower than expected in several odorous areas. Some corrosion is noted on odor piping. Since air flows are reduced from expectation, it is possible this is the result of reduced fan performance, increased headloss in the system, or other mechanical conditions.
Structural Condition	Cracks noted in Odor Control Building and basin. H_2S exposure noted at odor control basins. Leaks noted in Odor Control Building concrete roof. Metal Odor Control Fan Room at the Old Headworks Building is at end of life.
Electrical Condition	Panelboards in Odor Control Building in fair condition.
Instrumentation Condition	Unclear if any instrumentation, for pressure or flow, exists on odor control ductwork and fans. If odor control air flows are crucial to NFPA code classification, considerations to monitor performance are warranted.

Item	Description
Operations Challenges	Plant staff are very happy with the performance of the biofilter; however, the specific cause of reduced air flows in various odor-controlled areas is unclear. Long-term, need to maintain odorous air flows to minimize process equipment corrosion and provide ventilation.
Future Needs	Evaluate odor control issues at BWRF after modifications to flow EQ. Consider conducting a new odor study. Provide odor control for new odorous processes, such as a new EQ basin, and consider routing nearby airflows such as primary clarifier and Old Headworks flows, to the new odor system.

2.6.1 Odor Control – Recommended Improvements

Recommended improvements include:

- Plan for odor study.
- Construct new odor control system at new EQ facility and combine nearby existing odorous air flows with the new facility.
- Evaluate existing odor control fans and air movement to ensure expected air flows are being achieved to mitigate odors and corrosion.

2.7 Solids Thickening

Solids thickening consists of a single DAF thickener and associated pumps for thickening WAS prior to digestion. The DAF thickener concrete tank was originally constructed in 1976 with subsequent modifications, including the addition of a metal building structure over the tank.

Primary sludge is thickened to the extent possible in the primary clarifiers and does not have further thickening prior to digestion.

Table 2.6 Solids Thickening Condition Summary

Item	Description
Initial Construction	The DAF thickener concrete tank was originally constructed in 1976.
Modifications History	The metal building structure and pumps have been added and modified in several projects.
Components	DAF tank, aeration, WAS feed pump, Thickened WAS (TWAS) Pump Station.
Mechanical Condition	No DAF feed pump redundancy, very tight access in below-grade retrofitted room. TWAS pumps have redundancy but limited access. Some DAF equipment in need of replacement.
Structural Condition	Metal building and structure in fair condition considering age. Limited egress in Pump Rooms. Loose handrails.
Electrical Condition	Recent MCC replacement but other transformers, panels, and conduits are in fair to poor condition.
Instrumentation Condition	Limited instrumentation present but what exists is at end of life.
Operations Challenges	Access and redundancy for feed, access to TWAS pumps. Staff like the DAF performance and lack of chemical addition.
Future Needs	Consider redundancy or alternative thickening approaches.

2.7.1 Solids Thickening – Recommended Improvements

Recommended improvements include:

- Provide new WAS thickening system due to age and redundancy limitations. DAF is a desirable alternative due to lack of chemical addition.

2.8 Digestion

The digestion process consists of three digesters, the Waste Sludge Pump Station, and two sludge holding tanks. All tanks were constructed prior to 1987 with some concrete as old as the 1950s. The Waste Sludge Pump Station was constructed in the 2001 Phase 1 Project. All biogas is currently flared. The flare and associated piping were constructed in 2007.

Currently, the digestion process is not providing complete anaerobic digestion due to some mechanical challenges and limited total volume. Currently, this is acceptable due to good dewatering performance and the ultimate destination of beneficial solids reuse via composting. However, age and capacity of the digesters are a limiting component for complete anaerobic digestion, beneficial biogas reuse, and options for solids reuse including achieving Class B biosolids. The shallow sludge holding tanks are former primary clarifiers with covers and large bubble compressed gas mixing, serving as a wide point in the line prior to dewatering.

Table 2.7 Digestion Condition Summary

Item	Description
Initial Construction	All tankage constructed prior to 1987, as old as the 1950s. Waste Sludge Pump Station constructed in 2001. Digester gas system and flare constructed in 2007.
Modifications History	Several minor piping, electrical, and architectural upgrades have been made through the years. The sludge holding tanks were originally primary clarifiers and were converted to sludge storage after 1987, with covers and mixing added later.
Components	Larger Digester 1, smaller Digesters 2 and 3, Sludge Holding Tanks 1 and 2, Waste Sludge Pump Station with compressors and dewatering feed pumps, digester gas flare.
Mechanical Condition	Piping and valving at digesters are at end of life, requiring repair and improvements to maintain operability. Manual draining of condensate from digester gas lines. Boiler uses natural gas for heating digesters and has not worked with digester gas since the biogas compressor has never functioned properly. Sludge pumps in poor condition and in need of replacement, only one pump was operable on day of assessment. Flare is operable.
Structural Condition	Significant H_2S exposure and concrete in poor condition at digesters, all of which are at end of life. Thin walls at sludge holding tanks approaching end of life. Digester Building concrete in fair condition, stair risers greater than 7 inches.
Electrical Condition	Digester 1 MCC and heat exchanger are newer and could be salvaged. Digester 1 Electrical Room had more recent upgrades circa 2009, but Digesters 2 and 3 Electrical Room is 1986 era and in poor condition due to age and environment.

Item	Description
Instrumentation Condition	Control system for boilers outdated. PLCs and other equipment generally at or beyond expected service life.
Operations Challenges	Digesters have capacity limitations to achieve target anaerobic retention time. Manual operations on condensate line.
Future Needs	New digestion complex.

2.8.1 Digestion – Recommended Improvements

Recommended improvements include:

- Construct a new digestion complex, including digesters, dewatering feed pumps, and pre-dewatering sludge storage.
- Consider capacity and desire to achieve Class B biosolids and beneficial reuse of biogas.

2.9 Dewatering

The Solids Process Building was constructed in the Phase 1 Project in 2001, and consists of two dewatering centrifuges, screw conveyors, truck loadout, polymer feed, centrate holding, and centrate pumping. Excess sludge storage in membrane sludge holding basin on south side of plant site is from 2007.

Centrifuges operate 6 days a week, ten hours per day. Dewatering performance is good. Staff have switched to liquid polymer which is preferred. Centrate storage is limited and insufficient for process needs, this is especially important because centrate nutrient levels are lower than anticipated due to digestion performance. If digestion performance is improved, centrate storage and treatment will be necessary to maintain liquid stream process capacity.

Table 2.8 Dewatering Condition Summary

Item	Description
Initial Construction	Solids Process Building constructed in 2001, Sludge Holding Basin constructed in 2007.
Modifications History	Conversion to liquid polymer occurred more recently. Conveyor replacements budgeted in 2023 using operation and maintenance (O&M) budget.
Components	Centrifuge dewatering, liquid polymer feed, conveyors, centrate storage and pumping.
Mechanical Condition	Centrifuges have some capacity limitations and are nearing 20 years old. Facility was setup for a third future centrifuge, but conveyor and centrifuge access are unclear. Centrate pumps wear out quickly in hard service. Centrifuge startup produces a lot of slop and the centrate tank is hard to access. Centrate lines have plugged and are difficult to clean without cleanouts. Excess sludge storage works, but cover and pump nearing end of life. Pump is manual and loud. Air movement limited, recommendation checking ventilation.
Structural Condition	Grating banding around centrifuges should be repaired. Structural otherwise in good condition.

Item	Description
Electrical Condition	MCCs and switchboard in fair condition, some recent electrical improvements in good condition.
Instrumentation Condition	Instrumentation and control panels in good condition.
Operations Challenges	Centrifuge operations require 6 full days due to centrifuge capacity. Consider larger capacity centrifuge replacements and increase centrate storage volume, improve centrate pumping and piping. Highly desirable by plant staff to have excess sludge storage volume.
Future Needs	Upgrade centrifuges for dewatering capacity, centrate treatment improvements in parallel with digestion upgrades.

2.9.1 Dewatering – Recommended Improvements

Recommended improvements include:

- Improve centrate storage, treatment, pumping, and distribution.
- Replace conveyors (currently scheduled in 2023).
- Replace centrifuges with larger capacity units or consider increasing to three operating centrifuges if mechanical connections and access can be defined.
- Plan for sludge storage volume and replacement of dewatering feed pumps.

2.10 Electrical Infrastructure

The overall electrical service infrastructure is in fair condition. The site has six major transformers as main power sources, owned by the electric utility (Xcel Energy [Xcel]). A prior arc flash study was conducted in 2016 which contained a few shortcomings. Specifically, the one-line diagrams do not include cable types, cable sizes, or cable length which are used for study calculations. It is also missing some utility information (e.g., the minimum and maximum available fault current, utility impedances, etc.). The protection device coordination study does not show time current curves graphically to indicate the coordination system. The study also does not clearly indicate the alternative device settings (or recommendations) to allow the Owner to select different functionalities of the system, improve coordination, and minimize the arc-flash energy by selective trip and time settings. Due to these shortcomings and the age of the study, it is recommended to plan to conduct a new arc flash study, including a short circuit evaluation table for equipment comparing their respective ratings with calculated maximum faults.

Currently, four backup generators serve as redundant power sources and are well maintained and regularly operated. Site lighting is in poor condition around the facility and should be replaced.

Recommended improvements include:

- Develop an updated full plant one-line diagram. Would be useful to document age of major equipment on this for replacement planning.
- Update arc-flash study and provide equipment labeling.
- Replace switchboard in West Generator Building.
- Replace interior lighting in hazardous areas with new LED lighting.
- Replace site lighting.
- Plan for future generator capacity needs and eventual replacement.
- Assess available power supply and distribution with future improvements.

2.11 I&C Systems

In general, the supervisory control and data acquisition (SCADA) system provides plant staff the operations control they desire. Most PLC panels look good and use ABB CompactLogix current edition products. PLC panels appear to have limited spare capacity. Pump protection could be upgraded to meet current design preferences. Several magnetic flow meters do not have recommended installation straight runs for best accuracy.

Recommended improvements include:

- Consider PLC and instrumentation upgrades in parallel with major construction projects.
- Increase trending for process control, especially for dissolved oxygen and IR rates to optimize denitrification.

2.12 Abandoned Infrastructure

The BWRF currently has only a modest amount of abandoned infrastructure, including an original headworks in the southwest corner of the site, portions of the Old Headworks Building adjacent to the primary clarifiers, and the old Influent Screw Lift Pump Station. Future improvements likely will result in the abandonment of other structures, such as the south train aeration basins and secondary clarifiers, existing digesters, sludge holding tanks, and DAF. Consideration for demolition and use of these interior areas of the plant site should be made for optimal use of the limited plant space and property.

Chapter 3

LIQUIDS STREAM EVALUATION

3.1 Introduction

This chapter comprises all liquid stream evaluations conducted as part of this Utility Plan. Future growth and regulatory requirements are described in Chapter 1 – Basis of Planning; and asset rehabilitation needs are described in Chapter 2 – Facility Assessment. The first section of the chapter summarizes the desktop and process modeling capacity analysis. An evaluation of the current hydraulic and treatment capacity of the existing BWRF under current and near-term anticipated discharge limits for effluent nutrients is presented. Influent flow and load assumptions for the capacity evaluation, and a detailed evaluation of future regulatory changes that may impact planning efforts, were adopted from the analyses summarized in Chapter 1. The latter half of this chapter summarizes the mainstream process alternatives evaluation. For applicable liquid stream treatment units, process alternatives initially considered by the project team are presented followed by an evaluation of shortlisted alternatives. The end of this chapter includes a discussion of new unit processes that are required for compliance with future Regulation 31 effluent limits, PFAS, and effluent temperature compliance.

Capital cost estimates, grouping of proposed liquid stream improvements, and design/construction sequencing considerations are later summarized in Chapter 7 – Recommendations for BWRF Improvements.

3.1.1 Objectives and Key Planning Drivers

The current capacity and liquid stream alternatives evaluation accomplished the following objectives:

- Evaluate facility-wide hydraulic and treatment capacities under currently permitted ADMMF design capacity.
- Summarize required upgrades to expand the treatment of the liquid stream to meet near-term discharge permit limits.
- Define treatment alternatives considering future flows, loadings, and regulatory requirements and conduct alternative analysis resulting in the identification of short- and long-term facility improvements.
- Evaluate alternatives based on ability to meet requirements defined in Chapter 1 – Basis of Planning and Broomfield's objectives as defined in the Executive Summary.
- Develop a general list of equipment and planning-level facility layouts for the identified treatment alternatives to be used for cost estimating in Chapter 7.

3.1.2 Organization

This chapter is structured as follows:

Section 3.2 provides a high-level overview of the existing liquid stream treatment process.

Section 3.3 presents the results for the liquid-stream treatment capacity analysis under current effluent permit limits and highlights capacity deficiencies that must be addressed as part of upcoming improvements projects.

Section 3.4 presents the results of the liquid-stream treatment technology alternatives assessment and the recommended improvements over approximately the next 10 years.

Section 3.5 presents, at a high-level, the future improvements likely required at the facility to meet forthcoming regulatory requirements like effluent temperature, Regulation 31, and PFAS.

Section 3.6 discusses current and future recommendations for odor control.

Section 3.7 provides a summary.

3.2 Existing Facility Description

The existing liquid stream treatment train consists of influent pumping, flow measurement, 1/4-inch mechanical stair screens, stacked tray grit removal, primary clarification, primary effluent flow EQ, IFAS secondary treatment with upstream anaerobic and anoxic basins, final clarification, and UV disinfection prior to discharge. The facility also operates an RWTF where secondary effluent is filtered, disinfected, and discharged to Broomfield's reclaimed water system.

The solids treatment train consists of dissolved air flotation thickening (DAFT) of WAS, mesophilic anaerobic digestion of primary solids and thickened WAS, sludge EQ, and centrifuge dewatering. The dewatered biosolids are hauled off-site, either for composting prior to land application at Broomfield's resource recovery farm near Gilcrest, CO or for privatized composting by third parties. The BWRF can also stabilize the WAS with sodium hypochlorite to meet Class B pathogen criteria prior to DAFT and centrifuge dewatering (bypassing anaerobic digestion); however, this has not been practiced in recent years.

A process flow diagram of the existing facilities is shown in Figure 3.1. Abbreviated summaries of existing liquid stream capacities are summarized in the following sections and in Appendix 3A.

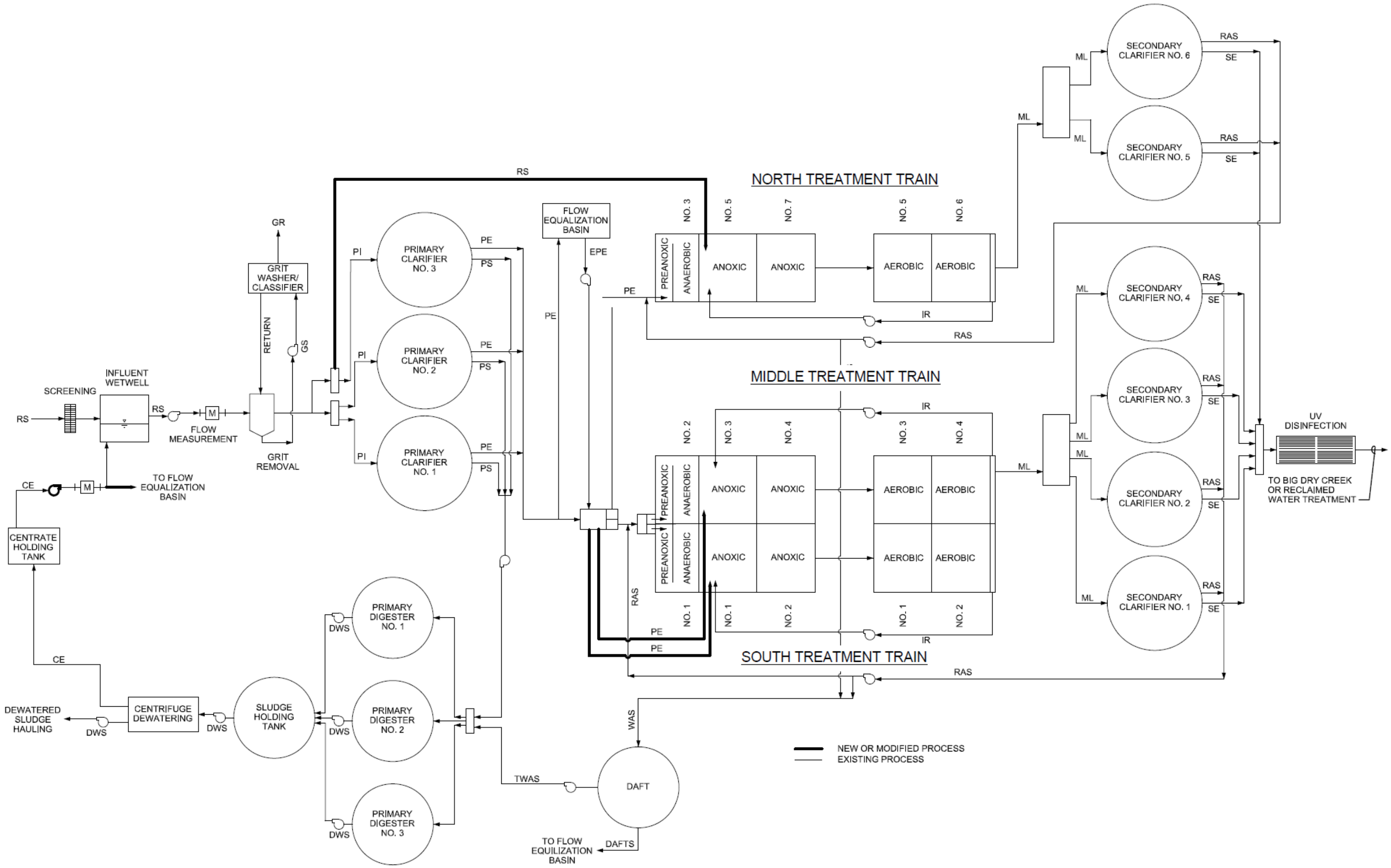


Figure 3.1 BWRF Existing Process Flow Diagram

3.3 Liquid Stream Treatment Capacity Analysis

3.3.1 Preliminary Treatment

Preliminary treatment consists of mechanical stair screens, screened wastewater lift pumps, stacked tray HeadCell® separators, and grit washer/classifiers. The stair screens are installed in the Screening Building, the screened wastewater pumps are installed in the Influent Pumping Station (IPS), and the stacked tray grit separator and grit washer/classifiers are housed in the Grit Removal Building.

Flow enters the site through one of two interceptors – one 36-inch and one 42-inch. Ferric chloride is added to the raw wastewater for odor control just prior to the point where the flow is directed through a 66-inch pipe to the Screenings Building, which is located upstream of the IPS and at the center of the treatment facility. The raw influent is screened using one of the two Vulcan stair screens with 1/4-inch (6-millimeter [mm]) openings designed to remove rags and debris that could otherwise damage downstream equipment. Each stair screen is equipped with a Vulcan washer/compactor to remove organic matter from the screenings and to compact the screenings prior to bagging and disposal in an adjacent dumpster. Screened wastewater enters a common wet well, where it is then lifted by influent pumps to the Grit Removal Building. Note that the influent screening channel is outfitted with two openings that allow passive overflow of raw wastewater around the screens and into the same covered wet well in case of emergency.

Six horizontal, screw-centrifugal pumps are used to lift the screened wastewater to the Grit Removal Building, with the ability to convey rags and solids up to 6 inches in diameter in case of emergency bypass of raw wastewater around the screens and into the wet well. The centrifugal pumps each have a capacity of 4,350 gallons per minute (gpm) (6.26 mgd). The influent wet well is equipped with an odor control exhaust connected to a centralized odor control system. The discharge of the screened wastewater pumps is equipped with two 20-inch magnetic flow meters for influent flow monitoring (it is noted that limited lay length for these flow meters may affect their performance). Screenings are conveyed into dumpsters on the main level of the Screening Building. In the Grit Removal Building, grit is removed using the Eutek vortex headcell chambers. The grit is processed through one of two grit washer/classifiers ("Slurrycup" and "Snail", both by Eutek) prior to collection for disposal at an offsite landfill.

From the grit removal process, the wastewater flows through a 42-inch diameter pipe to the original Headworks Building, where the flow is either split to the primary clarifiers or sent directly to the anoxic zone of the North Treatment Train to improve carbon availability for nutrient removal. Historically, primary bypass is not operated due to scum accumulation in the IFAS media screens.

A summary of preliminary treatment design criteria is presented in Table 3.1.

Table 3.1 Preliminary Treatment Design Criteria

Process/Equipment	Units	CDPHE Design Criteria(1)	Criteria / Capacity
Mechanical Bar Screens			
Number	-	-	2
Nominal Channel Width	feet	-	4
Bar Spacing	inch	0.25-1.75	0.25 (6 mm)
Maximum Velocity through Screens	ft/sec	<3 through screen at PHF	1.7(2)

Process/Equipment	Units	CDPHE Design Criteria(1)	Criteria / Capacity
Design Maximum Flow, each	mgd	-	20.3(2)
Total Maximum Flow Capacity	mgd	-	40.6
Firm Capacity	mgd	Shall meet design PHF	20.3
Screened Wastewater Lift Pumps			
Number	-	-	6
Type	-	-	Horizontal, screw-centrifugal
Capacity, each	mgd	-	6.26(3)
Total Capacity	mgd	-	37.6
Firm Capacity	mgd	Shall maintain wet well water surface level below design maximum high level (alarm level)	31.3
Influent Flow Measurement			
Number	-	-	2
Type	-	-	20-inch magnetic flow meters
Total Capacity	mgd	Able to function over the full range of expected design flows	Emerson/ Rosemount scaled 0 to 32 mgd
Grit Removal System			
Number	-	-	2
Type	-	-	Eutek Headcell
Volume, each	cf	-	4,600
Tray Diameter	feet	-	12
Number of Trays, each	-	-	9
Fixed Capacity	mgd	Designed in accordance with the manufacturer's recommended velocity and detention time through the chamber	32(3)(4)
Number of Grit pumps	-	-	4
Grit Pump Capacity, each	gpm	-	335 @ 26 feet rated head

Notes:
(1) State of Colorado Design Criteria for Domestic Wastewater Treatment Works (CDPHE, 2022).
(2) Design criteria adopted from the Process Design Report of the "Phase 2 Expansion of the Broomfield Wastewater Reclamation Facility" (Black & Veatch, 2007).
(3) Design criteria adopted from Table 4-4 of the 2011 Wastewater Utility Plan Update (Black & Veatch).
(4) Design value could not be verified against the Process Design Report of the "Phase 2 Expansion of the Broomfield Wastewater Reclamation Facility" (Black & Veatch, 2007).
ft/sec feet per second

Based on the available information presented Table 3.1, the existing preliminary treatment system has a rated peak hour flow capacity of approximately 20.3 mgd based on the mechanical stair screens. Per the State of Colorado Design Criteria for Domestic Wastewater Treatment Works (WPC-DR-1) (CDPHE, effective June 7, 2022), the firm capacity of screening facilities (one unit out of service) must meet design peak hour influent flow. Overflow or bypass to a redundant flow channel, capable of carrying the design peak hour flow, must occur automatically through a gravity overflow if the primary screen fails or becomes overloaded. For a facility with multiple screening devices like BWRF, the overflow or bypass channel does not require a screen. It is unclear currently what the passive overflow capacity is of the two openings in the existing screenings channel. It is also important to note that there is a discrepancy between the rated capacity noted in the Process Design Report of the Phase 2 improvements and the 2011 Wastewater Utility Plan Update (Black & Veatch). The Process Design Report calls out a design maximum flow of 20.3 mgd (each) while the 2011 Wastewater Utility Plan Update indicates a peak instantaneous and equivalent maximum month capacity of 32 mgd and 12.3 mgd, respectively, for the influent screening process. This should be more closely evaluated as part of any future process design report or re-rating of the facility.

The fixed capacity of the grit removal system has a peak instantaneous and equivalent maximum month capacity of 32 mgd and 12.3 mgd, respectively, per the 2011 Wastewater Utility Plan Update (Black & Veatch). This capacity agrees with the firm capacity of the screened wastewater lift pumps; however, the grit system capacity could not be found in the Process Design Report of the Phase 2 improvements. This should be more closely evaluated as part of any future process design report or re-rating of the facility.

3.3.2 Primary Treatment

Primary treatment consists of three parallel primary clarifiers (two octagonal (built circa 1987) and one circular (built circa early 2000s)), which remove readily settleable and floatable solids from the screened wastewater prior to secondary treatment. The two octagonal primary clarifiers are 70-foot diameter with 7.75-foot side water depth (SWD). The circular primary clarifier is 95-foot diameter with a 15-foot SWD. All units are covered and equipped with odor control for headspace exhaust air. The clarified liquid stream, called primary effluent, is transferred to one of three secondary treatment trains or to the EQ basin.

The solids removed during the primary clarification process (called primary solids) are pumped to the primary digesters. Four primary sludge pumps are connected to a suction header in the Primary Sludge Pumping Station (PSPS). Primary scum is collected from all three clarifiers and piped by gravity to a wet well, which is then connected by a suction pipe to a scum pump in the PSPS.

A summary of primary treatment design criteria is presented in Table 3.2.

Table 3.2 Primary Treatment Design Criteria

Process/Equipment	Units	CDPHE Design Criteria[1]	Criteria/Capacity
Primary Clarifiers			
Number	-	-	3
Diameter, each	feet	-	2 @ 70 1 @ 95
Surface Area, each	sf	-	2 @ 3,980 1 @ 7,088
Weir Length, each	feet	-	2 @ approx. 209 1 @ approx. 278

Process/Equipment	Units	CDPHE Design Criteria(1)	Criteria/Capacity
SWD	feet	>10	2 @ 7.75 1 @ 15
ADMMF Capacity	mgd	800 to 1,200 gpd/sf SOR	12.0 to 18.0(2)
PHF Capacity	mgd	2,000 to 3,000 gpd/sf SOR	30.1 to 45.1(2)
	mgd	10,000 gpd/ft to 40,000 gpd/ft (weir loading) at PHF	7.0 to 27.8(3)
Primary Sludge Pumps			
Number	-	-	4
Capacity, each	gpm	-	120
Total Capacity	gpm	-	480
Primary Scum Pump			
Number	-	-	1
Total Capacity	gpm	-	120

Notes
(1) State of Colorado Design Criteria for Domestic Wastewater Treatment Works (CDPHE, 2022).
(2) Flow capacity calculated based on all primary clarifiers in service and assuming minimum and maximum SOR recommended by CDPHE.
(3) Flow capacity calculated based on all primary clarifiers in service and assuming minimum and maximum weir loading rate recommended by CDPHE.
gpd/sf gallons per day per square foot
sf square foot
SOR surface overflow rate

Based on the above design criteria, the existing primary clarifiers are theoretically and operationally sufficiently sized based on surface overflow rate for the current permitted hydraulic capacity of the facility and could potentially accommodate a future hydraulic capacity increase based on the SOR up to an ADMMF and PHF of 18 mgd and 45.1 mgd, respectively. Note, however, that the SWD of the two smaller clarifiers (PC 1 and PC 2) does not meet the CDPHE WPC-DR-1 criteria of 10 feet. Furthermore, the existing total weir length of approximately 696 feet does not provide sufficient PHF capacity (per CDPHE WPC-DR-1) to meet the current rated value of 31.2 mgd (calculated value of only 27.8 mgd).

It is likely that CDPHE would grant a site-specific deviation for the existing SWD and weir length as part of a future improvements project. Furthermore, the facility has a well-known and documented carbon limitation in the secondary treatment system; this is generally attributed to enhanced removal of BOD_5 and COD due to chemical solids residuals discharged from the drinking water treatment facility and the addition of ferric chloride to the raw influent for odor control. As such, operations staff has historically operated with one or more primary clarifiers out of service in attempts to push more colloidal and particulate carbon through primary treatment and into the secondary treatment system to support biological nutrient removal.

Adjusting the number of primary clarifiers in service will effectively change the hydraulic retention time (HRT) through the online units. Figure 3.2 illustrates the typical relationship between TSS and BOD_5 removal for different influent TSS and BOD_5 concentrations versus HRT for primary treatment, as published in literature (Metcalf & Eddy, 5th Edition). This illustration indicates that as the HRT decreases, BOD_5 removal (solid line) also decreases (thereby increasing carbon availability downstream for nutrient removal). A review of plant data from

2014 to present suggests only a minor relationship between lower primary clarifier HRTs and lower secondary effluent nitrate concentrations. Nonetheless, BOD_5 removal in the primaries does show some positive correlation with HRT (Figure 3.2), but the spread of the calculated percent removal values remains high across the available data set.

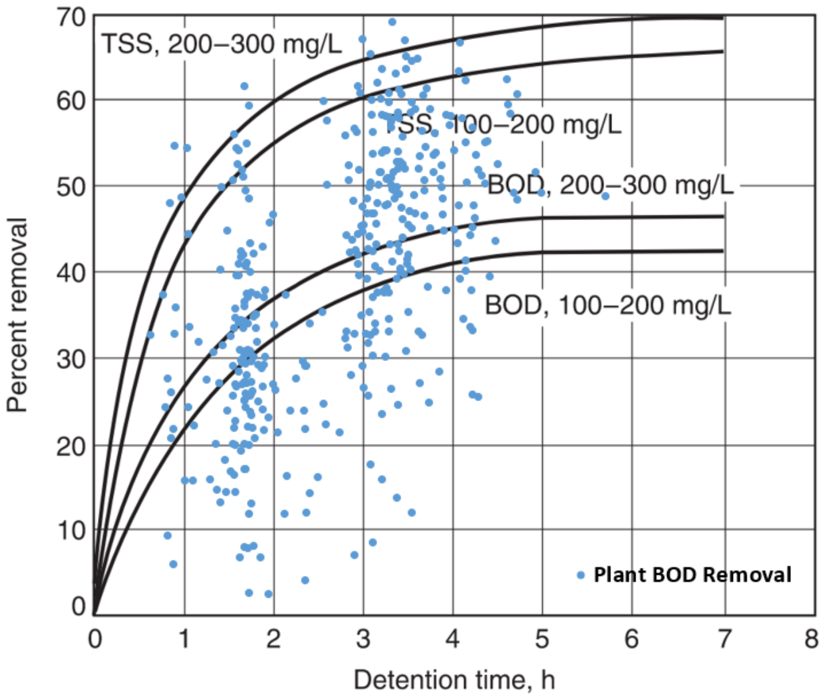


Figure 3.2 Typical TSS and BOD_5 Removal vs. HRT for Primary Clarifiers

3.3.3 Flow Equalization

Effluent from the three primary clarifiers recombines and flows by gravity in a 42-inch pipe to the Primary Effluent Splitter Box, located immediately upstream of the unaerated secondary treatment basins. The flow diversion structure contains two sets of electrically actuated gates and weirs that split flow between the secondary treatment trains. Operators generally strive to establish and maintain a steady flow rate through the downstream treatment processes at this splitter box, using a flow EQ basin to shave daily high flow peaks and to augment low diurnal flows. During peak diurnal flows, a tee and motorized plug valve in the 42-inch pipe upstream of the splitter box is actuated to allow flow above a predetermined set point to be diverted to the flow EQ basin. A second tee in the 42-inch pipe accepts pumped flow from two EQ return pumps (2 mgd return flow capacity, each, operated on VFDs for returning temporarily stored primary effluent to the splitter box).

The EQ basin has a total capacity of approximately 2 million gallons (MG) split between two hydraulically connected storage tanks (1.3 MG and 0.7 MG). The larger EQ storage tank is equipped with coarse bubble diffusers, which provide air to the basin via two 1,000-standard cubic feet per minute (scfm) blowers; the smaller tank does not contain any mixing or aeration equipment (due to infrequent use and need).

Based on the 2011 Wastewater Utility Plan Update (Black & Veatch), the existing EQ tanks have capacity to shave the current design PHF from 31.2 mgd down to an EQ peak flow of 18.6 mgd.

3.3.3.1 Verification of Existing EQ Capacity

There was no information readily available for how the capacity of the EQ system was originally calculated or permitted. Therefore, Carollo conducted an independent analysis of the system as part of this Utility Plan. While this analysis was preliminary and based on spreadsheet calculations in lieu of using modeling software (i.e., AFT Fathom), it provides a semi-quantitative verification of past design assumptions. This analysis occurred at an opportune time, as the BWRF had experienced a wet weather rain event that dropped over 3 inches of rain in Broomfield on August 16, 2022. As a result, the facility observed an extreme peak diurnal flow event through the treatment system. The diurnal flow profile from that day was adopted and normalized for investigating the PHF capacity of the existing EQ tankage (Figure 3.3).

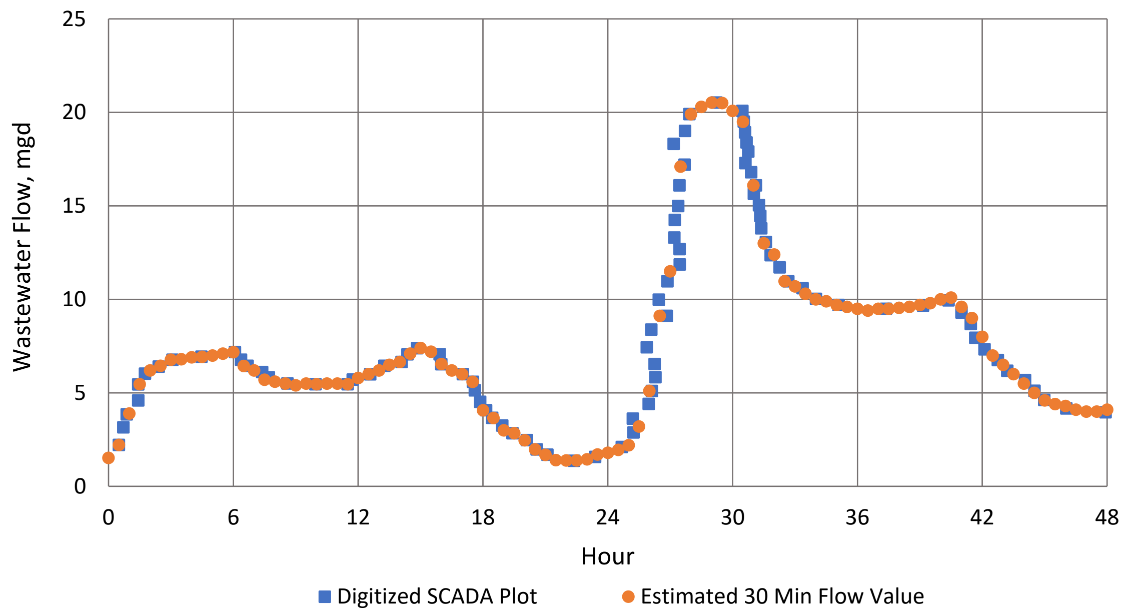


Figure 3.3 Peak Wet Weather Diurnal Flow Profile from August 16, 2022

Using a normalized flow curve from the data presented above, the existing 2 MG of EQ volume could theoretically equalize the current design PHF of 31.2 mgd down to approximately 17.2 mgd (Figure 3.4); this agrees with the previously noted EQ peak design flow of 18.6 mgd. Note that this preliminary analysis included the following assumptions, which should be more closely scrutinized as part of designing the future EQ tank system:

- The EQ basins were empty at the time of the peak wet weather event.
- The yard piping to the EQ basin and the upstream flow diversion equipment could reasonably convey the bypassed flows via gravity to the EQ basins without backing up into the upstream unit processes.

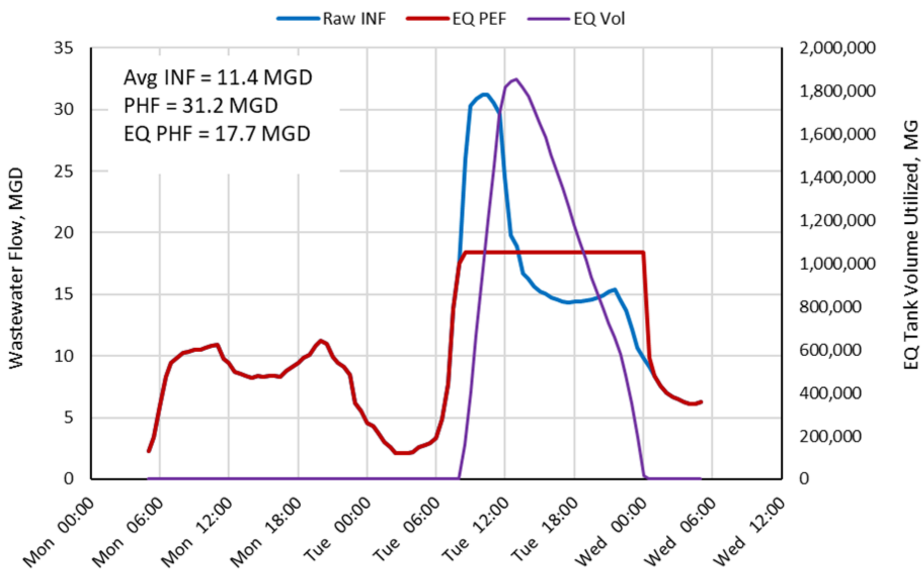


Figure 3.4 Theoretical Capacity of Existing EQ Basins at PHF of 31.2 mgd

3.3.4 Secondary Treatment

Primary effluent and EQ return flows are split at the Primary Effluent Splitter Box between three parallel secondary treatment trains – the North Train, Middle Train, and South Train. Flow is diverted directly from the Primary Effluent Splitter Box to the North Train, while flow to the Middle and South Trains must be split once more in a subsequent diversion structure. As part of a Biological Nutrient Removal Enhancements project in 2014, additional flow routing flexibility was installed such that a portion of the primary influent or primary effluent can be bypassed around the pre-anoxic and anaerobic zones to the anoxic zones to improve denitrification. The north anoxic zone can receive primary influent via a telescoping valve installed in the primary influent splitter structure, while the Middle and South Trains' anoxic zones can receive primary effluent via two telescoping valves installed in the facility's main secondary process splitter structures. In theory, the telescoping valve elevations and pipe sizing is based on a bypass flow of approximately 25 percent of each treatment train's ADMMF capacity.

Each treatment train is outfitted with dedicated unaerated basins followed by aerated IFAS reactors. The unaerated basins are cast-in-place concrete tanks, each of which consists of four unaerated zones in series (pre-anoxic, anaerobic, and two anoxic) separated by baffle walls. Each unaerated zone is equipped with either submersible or floating mixers to keep solids in suspension as the mixed liquor flows through the unaerated zones in a serpentine pattern. RAS from the secondary clarifiers is introduced in the pre-anoxic zone with primary effluent, while IR from the aerated IFAS reactors is returned to the first anoxic zone.

In 2023, a carbon addition storage and pumping facility designed to utilize MicroC 2000® for supplemental carbon addition was commissioned. This facility is located in the Old Headworks Building and includes carbon dosing options for the anaerobic and anoxic zones of each train. Carbon dosing is used by operations staff to achieve compliance with daily maximum TIN limits and maximize voluntary incentive program credit.

From the unaerated zones, mixed liquor flows into its dedicated IFAS basins. The IFAS basins are cast-in-place concrete tanks that are open to the atmosphere, with each IFAS train split into two reactors operated in series. High-density polyethylene plastic media is suspended in the bulk liquid of the IFAS basin as biofilm carrier elements. Ordinary heterotrophic organisms and nitrifying bacteria performing the aerobic treatment are attached to the plastic media, as well as circulating freely within the bulk liquid. The discharge side of each IFAS reactor is equipped with submerged, horizontal cylindrical stainless steel sieve screens that allow mixed liquor to exit the reactor but retain the plastic media and attached biomass growth.

The floor of each IFAS reactor is equipped with a stainless steel, medium bubble, aeration grid. The diffused air system provides oxygen to the biomass and mixing energy for the reactor. The South and Middle trains are equipped with four aeration blowers (four variable-speed turbo blowers, two each of two sizes) and the North train is equipped with five aeration blowers (two variable-speed turbo blowers and three multi-stage centrifugal). The variable-speed turbo blowers were installed circa 2015 as part of a BNR Enhancements project to provide improved turndown capabilities during low influent flow conditions and to reduce oxygen poisoning in the unaerated zones (which inhibits biological phosphorus removal and denitrification performance). Dissolved oxygen (DO) probes were installed in each aerated basin, with control valves provided on individual drop legs. Despite those improvements, the facility has continued to struggle with excessively high DO concentrations in the second IFAS reactor of each treatment train (>6 mg/L DO) until recent aeration control improvements were implemented as part of this Utility Plan. As of today, each IFAS reactor can more consistently maintain a target setpoint of 4 mg/L DO.

From the IFAS reactors, mixed liquor is conveyed to six secondary clarifiers (two dedicated per train). In the South and Middle Trains, mixed liquor flows to a four-way splitter structure where it is proportionately distributed between four secondary clarifiers. In the North train, mixed liquor flow over two weirs where it is proportionately distributed between two dedicated secondary clarifiers. Each clarifier is equipped with a spiral scraper mechanism and a center hopper for collection of the settled solids as RAS. The RAS is removed from the clarifiers via pumps located in the lower pipe galleries of the adjacent IFAS basins. WAS and floating scum from the clarifiers is conveyed to the DAF sludge thickening facility for solids handling. Clarified effluent (secondary effluent) is collected in the effluent launders and piped to the UV Disinfection Facility.

A summary of secondary treatment design criteria is presented in Table 3.3. Modeled aeration basin and secondary clarifier performance is further discussed as part of the BioWin process modeling summary provided in subsequent sections.

Table 3.3 Secondary Treatment Design Criteria

Process/Equipment	Units	CDPHE Design Criteria(1)	Criteria/Capacity(2)
Aeration Basins Volumes			
South Train			
Pre-anoxic	cf	-	6,757
Anaerobic	cf	-	11,311
Anoxic (Pass 1)	cf	-	11,311
Anoxic (Pass 2)	cf	-	12,159
IFAS (Reactor 1)	cf	-	36,890
IFAS (Reactor 2)	cf	-	36,890
SWD	feet	-	16.2

Process/Equipment	Units	CDPHE Design Criteria(1)	Criteria/Capacity(2)
Middle Train			
Pre-anoxic	cf	-	8,084
Anaerobic	cf	-	13,298
Anoxic (Pass 1)	cf	-	13,298
Anoxic (Pass 2)	cf	-	14,360
IFAS (Reactor 1)	cf	-	43,945
IFAS (Reactor 2)	cf	-	43,945
SWD	feet	-	16.2
North Train			
Pre-Anoxic	cf	-	6,525
Anaerobic	cf	-	11,963
Anoxic (Pass 1)	cf	-	13,050
Anoxic (Pass 2)	cf	-	11,238
IFAS (Reactor 1)	cf	-	40,800
IFAS (Reactor 2)	cf	-	40,800
SWD	feet	-	16
Total Number of Trains	-	-	3
Total Basin Volume	cf	-	376,624
	MG	-	2.82
Total Pre-Anoxic Zones	-	-	3
Volume	MG	-	0.16
HRT @ Design ADMMF	Min(2)	No criteria given for pre-anoxic zones	19
Percent of Total Volume	%	-	6
Total Anaerobic Zones	-	-	3
Volume	MG	-	0.27
HRT @ Design ADMMF	Min(2)	>120 (per Section 7.11.0.b)	33
Percent of Total Volume	%	-	10
Total Anoxic Zones	-	-	6
Volume	MG	-	0.56
HRT @ Design ADMMF	Min(2)	>120 (per Table 7.9)	68
Percent of Total Volume	%	-	20
Total IFAS Zones	-		6
Volume	MG		1.82
HRT @ Design ADMMF	Hours(2)	>4 (per WEF MOP 8 at 12 degrees C)	3.6
Percent of Total Volume	%		65
IFAS Media Criteria			
Type	-	-	Kaldnes (Kruger) K1
Effective Surface Area	m^2/m^3	-	500
Bulk Media Fill Fraction	%	<65	30

Process/Equipment	Units	CDPHE Design Criteria[(1)]	Criteria/Capacity[(2)]
Aeration Diffusers Criteria			
Type	-	-	Kruger Medium Bubble
Alpha Value	-	-	0.75 and 0.8 in IFAS Reactors 1 and 2, respectively
Standard Oxygen Transfer Efficiency	%/foot		1.1 to 1.5
Aeration Blowers			
South and Middle Trains			
Total No. of Unit	-	-	4 (3 duty, 1 standby)
Type	-	-	High-speed turbo
Capacity, each	scfm	-	2 @ 5,200 2 @ 2,600
Capacity, Total	scfm	-	15,150
Capacity, Firm	scfm	Must be capable of maintaining 2 mg/L DO in mixed liquor at all times for ADMMF condition.	9,950
Horsepower, Each	hp	-	2 turbos @ 400 2 turbos @ 250
Design Pressure	psig	-	8
North Train			
Total No. of Unit	-	-	5 (2 duty, 3 standby)
Type	-	-	2 high-speed turbo 3 multi-stage centrifugal
Capacity, each	scfm	-	2 turbo @ 5,200 3 multi-stage @ 2,600
Capacity, Total	scfm	-	18,200
Capacity, Firm	scfm	Must be capable of maintaining 2 mg/L DO in mixed liquor at all times for ADMMF condition.	13,000
Horsepower, Each	hp	-	2 turbo @ 400 3 multi-stage @ 150
Design Pressure	psig	-	8
IR Pumping			
Number	-	-	4 – Middle and South Trains 3 – North Train
Type	-	-	Vertical, non-clog, end suction centrifugal
Capacity, Each	mgd	-	7.1
Capacity, Total	% of Train Flow	200 to 400	Approximately 350 per train

Process/Equipment	Units	CDPHE Design Criteria(1)	Criteria/Capacity(2)
Secondary Clarifiers			
Number of Clarifiers	-	Multiple independently operating units	1 – Octagonal 5 – Circular
Diameter	feet	-	60 (SC 1, SC 2) 85 (SC 3) 80 (SC 4, 5, 6)
Surface Area, each	sf	-	2,830 (SC 1, SC 2) 5,060 (SC 3) 5,030 (SC 4, 5, 6)
Total Surface Area	sf	-	25,810
SWD	feet	13	10 (SC 1, SC 2) 12 (SC 3) 15 (SC 4, 5, 6)
RAS Pumps			
Number of Pumps	-	-	6
Type	-	-	Aurora
Drive	-	-	VFD
Capacity, each	mgd	-	3 @ 2.7 (Middle & South) 2 @ 1.3 (Middle & South) 3 @ 2.3 (North)
Firm Capacity/ Total Capacity	mgd	-	8 / 10.7 (Middle & South) 4.6 / 6.9 (North)
Firm RAS Flow Capacity as % of ADMMF Design Flow	%	100 to 150% of ADMMF	100% in Middle & South 115% in North
WAS Pumps			
Number of Pumps	-	-	6 (Middle & South) 3 (North)
Type	-	-	Netzsch
Capacity, each	gpm	-	125 gpm
Total Capacity	gpm	-	750 gpm (Middle & South) 375 (North)

Notes:
(1) State of Colorado Design Criteria for Domestic Wastewater Treatment Works (CDPHE, 2022), unless specifically noted otherwise.
(2) Calculated assuming forward flow without recycle flows.
hp horsepower
psig pounds per square inch gauge

3.3.4.1 Secondary Treatment Capacity Evaluation under Current Permit Limits

The analysis of the secondary treatment capacity is detailed in Appendix 3B along with the BioWin process modeling approach, assumptions, and results. Note that the capacity evaluation was previously conducted as part of the BWRF Carbon Addition Design Project (Carollo, 2021). As part of this Utility Plan, that same process model was re-validated for use in the alternatives analyses described below; the validation results are presented in Appendix 3C. The validation resulted in very minor tweaks to the original calibration, but none significant enough to change the findings of the original capacity analysis modeling. Briefly, the following design parameters were selected in coordination with operations staff for the capacity evaluation of the secondary treatment system under current permit limits.

- Design ADMMF = 12 mgd (24,020 ppd as BOD_5).
- Primary clarifier removal; BOD_5 = 40 percent, TSS = 70 percent.
- All treatment trains in service, with DO concentration of 4 mg/L.
- All secondary clarifiers in service.
- Wastewater temperature = 13.6 degrees C.
- Maximum mixed liquor suspended solids (MLSS) concentration = 3,500 mg/L based on verbal discussion with plant staff.

The simulated secondary treatment capacity at the rated design ADMMF flow and loads is presented in Table 3.4. The steady-state modeling results demonstrate that the rated design ADMMF flow and organic load are appropriate given the existing facility's current installed infrastructure. Increasing the hydraulic or organic treatment capacity through a site application amendment with CDPHE to meet anticipated growth is not feasible without capital improvements to the liquid stream processes. Specifically, at design organic and nutrient loading loads the liquid stream facility is nearing or is at capacity for the following parameters in the model:

- **Aerobic Solids Retention Time (aSRT) in Winter:** At the maximum MLSS of 3,500 mg/L, the calculated aSRT of the system (including estimated biofilm on the carrier media) is approximately 6.3 days at 13.6 degrees C. For reference, a design winter aSRT of 7.9 days is listed in the *Summary of Input and Output Parameters for Black & Veatch IFAS Model* (Black and Veatch, Phase 2 Upgrade and Expansion of the BWRF, 2007). The aSRT required in IFAS is less than would be required for a conventional activated sludge process because the biomass on the media is immobilized and "trapped" in the aeration zone. The modeled aSRT above for a minimum water temperature of 13.6 degrees C is consistent with other IFAS facilities operating in similar climate and is considered acceptable. It is not recommended to further encroach on this aSRT without additional biofilm/biomass data to justify the current operational aSRT onsite.
- **Effluent Nutrient Concentrations:** The modeled effluent TIN concentration exceeds the Regulation 85 running annual median limit of 15 mg/L and exceeds the daily maximum limit of 14 mg/L listed in the recent permit renewal. Modeled effluent TP concentration is just below the Regulation 85 running annual median limit of 1 mg/L. The facility can dose MicroC 2000, which was not assumed in this modeling effort. Dosing the external carbon would reduce effluent nutrient concentrations but would simultaneously increase the biomass inventory in the treatment trains – thereby reducing the modeled treatment capacity.

  An important note is that the current and future performance of the solids handling processes remains uncertain. Increased biomass loading to the existing digestion system resulting from increased organic loading, without capital improvements to improve treatment robustness and operability, puts the facility at further risk of equipment failure and variable nutrient recycle loads back to the liquid stream. Furthermore, the current HRT of the unaerated and aerated zones is at the minimum of typical design criteria in literature and as published in WPC-DR-1. The design HRT would be further reduced if the existing facility is hydraulically re-rated.

- **Firm Aeration Blower Capacity:** Per CDPHE guidance in WPC-DR-1, aeration blowers must have sufficient capacity to provide the required aeration rate for biological treatment with the largest single unit out of service. Based on the capacity modeling presented above and the aeration system design parameters provided by Veolia (e.g., alpha and oxygen transfer efficiency), the estimated aeration demand in the North Train and the combined Middle and South Trains are 5,413 scfm and 11,017 scfm, respectively. For comparison, the total and firm blower capacities currently installed at the BWRF are:
  - North Treatment Train:
    - Two high-speed turbo blowers, with total and firm capacity of 10,400 scfm and 5,200 scfm, respectively. Note that there are three multi-stage centrifugal blowers installed in the North, but operations staff does not run those blowers in parallel with the high-speed turbo units. This is likely because the centrifugal blowers are not required for capacity and are less efficient than the high-speed turbo blowers. It is uncertain how the two blower technologies work in conjunction.
  - South Treatment Train:
    - Four high-speed turbo blowers of two sizes, with total and firm capacity of 15,600 scfm and 10,400 scfm.

Because the modeled aeration demand slightly exceeds the firm aeration capacity of the system under the assumptions listed above, Carollo recommends that Broomfield not pursue an organic capacity re-rating at this time without further evaluation of blower capacity.

Table 3.4 Modeled Secondary Treatment Capacity Inputs and Outputs

Parameter	Unit	CDPHE Guidance Criteria(1)	BioWin Model Outputs and Inputs
Influent			
Flow	mgd	-	12
COD	ppd (mg/L)	-	52,276 (520)
BOD_5	ppd (mg/L)	-	24,020 (239)
TSS	ppd (mg/L)	-	40,682 (405)
VSS	ppd (mg/L)	-	33,761 (336)
TKN	ppd (mg/L)	-	4,706 (47)
NH_4	ppd (mg/L)	-	3,624 (36)
pH	S.U.	-	7.5
Alkalinity	mg/L as $CaCO_3$	-	235
Temperature	degrees C	-	13.6
Primary Clarifiers			
BOD_5 Removal	%	-	40
Effluent BOD_5	ppd (mg/L)	-	14,622 (145)
TSS Removal	%	-	75
Effluent TSS	ppd (mg/L)	-	10,282 (102)
Primary Sludge Flow	mgd	-	0.066
Primary Sludge TS	ppd	-	30,848
Primary Sludge VS	ppd	-	25,321

Parameter	Unit	CDPHE Guidance Criteria(1)	BioWin Model Outputs and Inputs
Aeration Basins			
Pre-Anoxic HRT(2)	hours	-	0.32
Anaerobic HRT(2)	hours	0.5-1.5	0.55
Anoxic HRT(2)	hours	1-3	1.1
Aerobic HRT(2)	hours	4-12	3.6
aSRT (including biofilm biomass)	days	-	6.3
North Train MLSS	mg/L	1,500-4,000	3,550
North Train MLVSS	mg/L	-	2,800
North Train Aeration Demand	scfm	Provide firm blower capacity at ADMMF	5,413
Middle & South Trains MLSS	mg/L	1,500-4,000	3,472
Middle & South Trains MLVSS	mg/L	--	2,737
South Train Aeration Demand	scfm	Provide firm blower capacity at ADMMF	11,017
North RAS Flow	mgd (%)	50-150% of influent flow	2.44 mgd (60)
North RAS TSS	mg/L	-	9,298
Middle and South RAS Flow	mgd (%)	50-150% of influent flow	4.68 (60)
Middle and South RAS TSS	mg/L	-	9,146
North WAS Flow	mgd	-	0.06
North WAS TSS	ppd	-	4,656
Middle and South WAS Flow	mgd	-	0.12
Middle and South WAS TSS	ppd	-	9,159
TWAS VS:TS	Ratio	-	0.79
North MLR Flow	mgd (%)	200-400%	3.3 (80)
Middle and South MLR Flow	mgd (%)	200-400%	6.0 (75)
Secondary Clarifier Operation(3)			
North Train SLR	ppd/sf	29	20
North Train SOR	gpd/sf	600	403
Middle & South Trains SLR	ppd/sf	29	23
Middle & South Trains SOR	gpd/sf	600	500

Parameter	Unit	CDPHE Guidance Criteria[1]	BioWin Model Outputs and Inputs
Secondary Effluent			
TSS	mg/L	-	6.2
Ammonia	mg/L	-	0.8
Nitrate	mg/L	-	16.2
Total Phosphorus	mg/L	-	0.9
Orthophosphorus	mg/L	-	0.7

Notes:
(1) State of Colorado Design Criteria for Domestic Wastewater Treatment Works (Water Pollution Control Program Policy No. WPC-DR-1, 2022).
(2) Recycle flows (e.g., MLR and RAS) are not included in the calculation of HRT.
(3) SOR and SLR are presented for the ADMMF condition only.
MLR mixed liquor recycle
MLVSS mixed liquor volatile suspended solids
SLR solids loading rate
VS volatile solids
VSS volatile suspended solids

Based on the calculated SOR and SLR of the secondary clarifiers with all units in service, the existing units have some excess ADMMF capacity when compared against the CDPHE design guidance in WPC-DR-1. A state point analysis (SPA) conducted on the secondary clarifiers indicates that the existing clarifiers could potentially handle the design equalized PHF of 18.6 mgd assuming a MLSS concentration of 3,500 mg/L and a sludge volume index (SVI) of 170 milliliters per gram (mL/g) (using the Daigger and Roper settling curve) (Figure 3.5). An SVI greater than approximately 170 mL/g could result in clarification failure if it happened to coincide with a peak flow event near the design capacity of the BWRF.

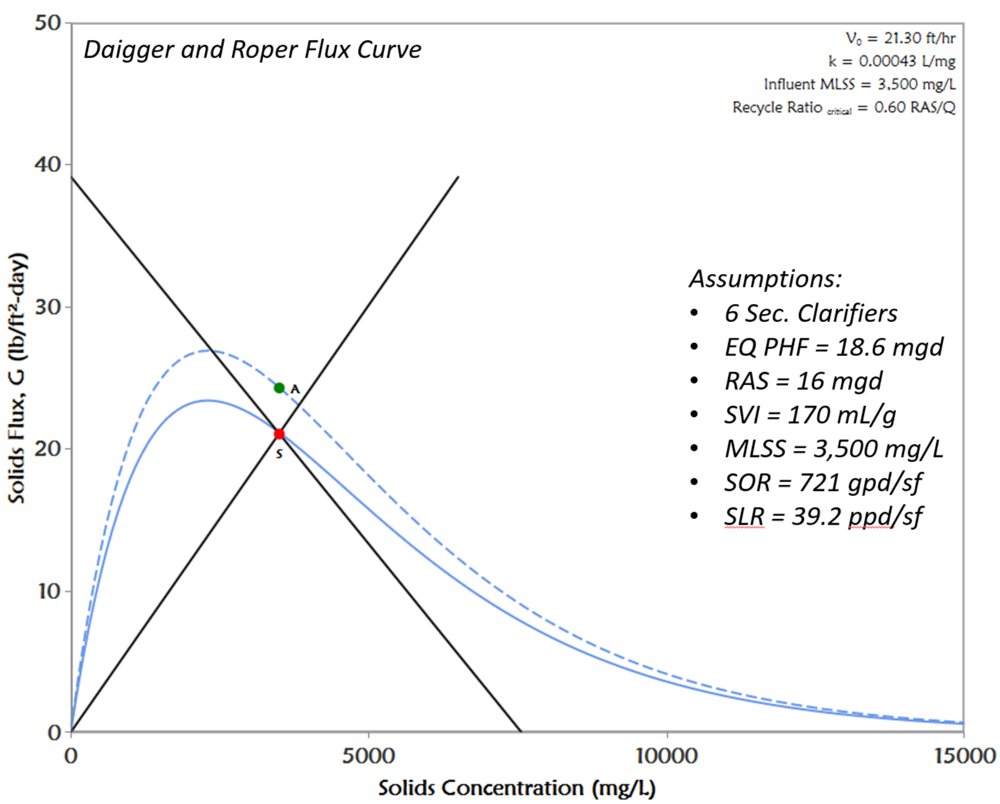


Figure 3.5 SPA of Existing Secondary Clarifiers at EQ PHF of 18.6 mgd and 170 mL/g SVI

3.3.4.2 Other Known Secondary Treatment Limitations and Considerations

Based on discussions with operations staff, the following limitations and considerations should be addressed as part of future improvements and treatment expansion on the liquid stream:

- The primary influent and primary effluent bypasses to the anoxic zones are unmetered and manually operated. Therefore, operations staff have not invested significant effort in carbon management/optimization using these tools because it is unclear how much flow is truly step-fed into the downstream zones.
  - Operations staff also prefer not to send primary influent to the anoxic zone of the North Train because it has historically resulted in increases scum and fats, oils, and grease accumulation in the IFAS reactors.
- The South Train has known hydraulic limitations, inadequate freeboard in the IFAS zones, shallow secondary clarifiers, and a crowded IR pump station that is extremely difficult for operations staff to service and maintain. For several years now, operations staff have left the South Train offline and prefer to limit operation of this train. The South Train and its dedicated clarifiers and IR pump station should either be significantly rehabbed or replaced as part of a future improvements project.
- The unaerated zones of the Middle and South Train are isolated from one another. It would be opportune if these zones could be hydraulically connected such that they could all be in service, even if a downstream IFAS train (e.g., the South Train) is offline. This may improve nutrient removal performance in the near- to mid-term.
- Known secondary treatment carbon limitation, higher DO concentrations in the IFAS reactors (typical design target of 4 mg/L), and existing unaerated zones that are on the smaller end of typical design HRT for increasingly stringent nutrient limits put the facility at risk of effluent compliance, especially if the existing solids handling process is improved to achieve Class B biosolids in the anaerobic digesters, resulting in higher nutrient concentrations in recycle streams. As such, Broomfield should consider:
  - Reserving capital budget for constructing sidestream nitrogen and phosphorus treatment of the digestate/centrate to reduce future nutrient loads to the liquid stream process.
  - Investigate opportunities to reduce the required DO concentration in the second IFAS zone in each treatment train to the greatest extent possible.
  - Optimization of IR rates in conjunction with carbon dosing.

3.3.5 Disinfection

Clarified effluent is recombined in the secondary clarifier effluent splitter structure, where it is then re-distributed to UV disinfection. The UV disinfection facility consists of an influent channel and three open channels fitted with Aquaray® 40 HO Gen2 Submersible (low-pressure, high-output) UV disinfection equipment (new as of 2021). The system is designed to maintain effluent *E. coli* counts in the treated effluent less than 235 colony forming units (CFU)/100 mL (daily maximum) and 126 CFU/100 mL (30-day geometric mean) at a peak design flow of 18.6 mgd (6.2 mgd per channel) (Table 3.5).

Table 3.5 UV Disinfection System Design Criteria and Capacity Rating

Process/Equipment	Units	CDPHE Design Criteria(1)	Criteria/Capacity
Number of Channels	--	-	3
Number of Banks per Channel	--	At least 2 banks in series per reactor channel	3
Design Capacity, total			
ADMMF	mgd	System shall be capable of disinfecting its proportionate share of the design maximum month flow with 1 bank out of service	12
PHF	mgd	Designed to treat PHF	18.6
Minimum UV Transmittance	% per cm	65	60
Design Dose	mJ/cm^2	30	Unknown

Notes:
(1) State of Colorado Design Criteria for Domestic Wastewater Treatment Works (CDPHE, 2022).
cm centimeter
mJ/cm^2 millijoules per square centimeter

3.3.6 Recycled Water Treatment Facility

The facility is currently outfitted with a RWTF for generating recycled water for Broomfield. Disinfected final effluent exits the UV Building by spilling over two sets of weirs in each of the UV channels and flowing into a 48-inch effluent pipe. The UV effluent is routed to a splitter structure in the RWTF, and the portion of the flow that is not directed to the filters is routed to the outfall basin for gravity discharge to the Big Dry Creek.

Based on the 2011 Wastewater Utility Plan Update (Black & Veatch), the RWTF has a nominal treatment capacity of 6 mgd and consists of three cells, each containing six continuous backwash sand filter modules. The desired flow rate for recycled water treatment is managed via a SCADA system controlled magnetic flow meter and electrically operated butterfly valve. Flow enters a rapid mix basin for chemical addition and exists over an effluent weir into a common inlet flume ahead of the filters. Each of the three filter cells is equipped with a filter inlet box and an influent butterfly valve to route flow to the bottom of the filters. Disinfected secondary effluent is filtered through the sand as it flows upward and discharges into a common filter outlet flume, which discharges through a 24-inch pipe to the recycled water pumping station. Sodium hypochlorite is normally added to the filtered effluent to maintain a residual in the recycled water distribution system.

For sake of the liquid stream capacity analysis, the RWTF is not included in the detailed analysis but is summarized for completeness of this chapter and the long-term CIP improvements (see Chapter 7).

3.3.7 Summary of Liquid Stream Capacity Evaluation

Based on this liquid stream capacity evaluation, all unit processes appear to be adequately sized for the facility's current permitted capacity through CDPHE (Figure 3.6). Note that hashed capacity bars indicate a potential range of treatment capacity depending upon interpretation of the historical design information or CDPHE's design criteria policy. There may be some excess capacity at individual unit processes, but a re-rating of the existing system for higher influent capacity is not recommended at this time because increased capacity cannot be reasonably demonstrated for the system (as a whole). Therefore, one or more capital improvements projects at each liquid stream unit process will be required within the planning horizon to increase the rated hydraulic and/or organic treatment capacity to meet future anticipated growth in Broomfield.

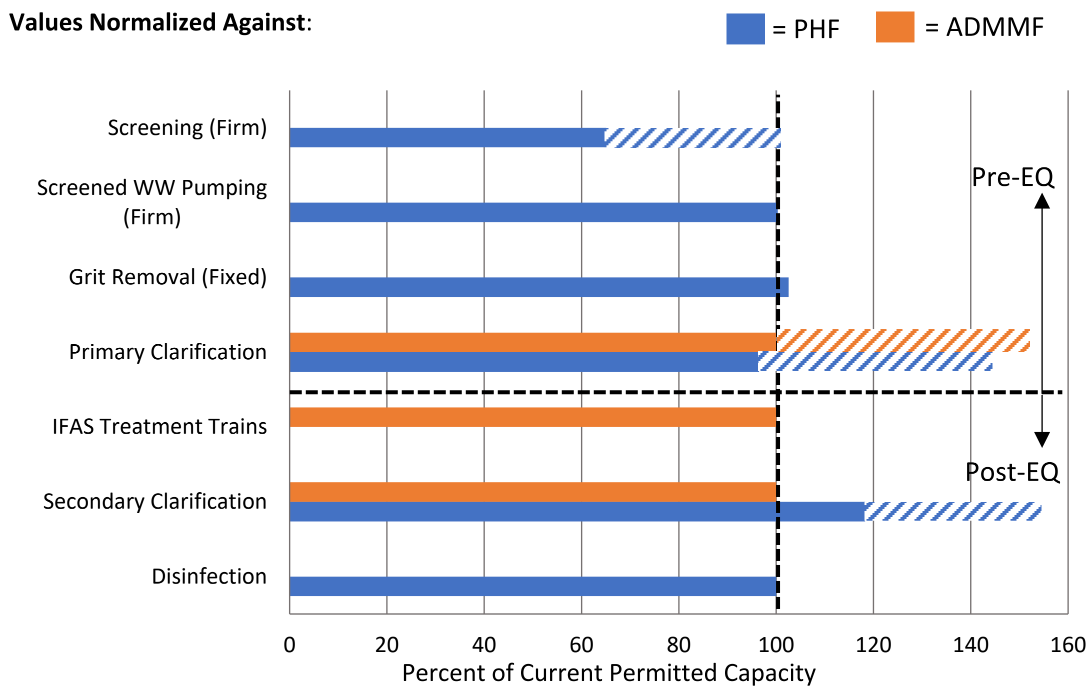


Figure 3.6 Simplified Summary of Current Liquid Stream Treatment Capacities

3.4 Liquid Stream Treatment Technology Alternatives Assessment

The following sections summarize the evaluation of each liquid stream unit operation and process alternative(s) identified by Broomfield's and Carollo's project team. Where needed, baseline improvements are recommended to meet the current and future planning conditions identified in Chapters 1 and 2, consisting of a combination of asset replacement needs and/or capacity improvements. The alternatives described below include a short narrative and justification. Cost information for each alternative and recommended project sequencing are provided in Chapter 7.

A summary of the assumed design flows and loads for the liquid stream alternatives assessment is provided in Table 3.6. The design concentrations were calculated from the projected flows and loads presented in Chapter 1. Rather than adopt the projected planning horizon average daily annual flow (ADAF) and ADMMF of 10.9 mgd and 13.4 mgd, respectively, the project team chose to size unit processes for an ADAF and ADMMF of 11.5 mgd and 14.0 mgd. In doing so, the facility would approach the 95 percent hydraulic capacity trigger for expansion at the planning horizon rather than rated capacity.

A PHF analysis was not conducted as part of this planning effort, as historical diurnal flow data were not available to analyze. Therefore, an influent PHF of 36.4 mgd was adopted assuming the current PHF:ADMMF peaking factor of 2.6. This should be revisited and more closely scrutinized as part of future conceptual design and facility re-rating efforts. An equalized PHF of 21.2 mgd was assumed downstream of primary treatment and flow EQ (see later sections in this chapter).

Table 3.6 Adopted Flows and Loads for Liquid Stream Alternatives Assessment

Parameter	Unit	ADAF Value	ADMMF Value
Influent Flow	mgd	11.5	14.0
Influent Load			
BOD_5	ppd	25,640	30,250
TSS	ppd	34,960	40,870
TKN	ppd	4,190	4,850
NH_4	ppd	3,250	3,450
TP	ppd	590	680
Design Concentration			
BOD_5	mg/L	267	259
TSS	mg/L	364	350
TKN	mg/L	43.8	41.5
NH_4	mg/L	33.9	29.5
TP	mg/L	6.2	5.8

3.4.1 Preliminary Treatment

Based on the capacity analysis presented above, capital improvements will be required to improve hydraulic conveyance and to increase equipment sizing prior to re-rating the current rated capacity of the facility beyond 12 mgd ADMMF (31.2 mgd PHF). This includes:

- Confirmation of existing screening equipment capacity with the manufacturer and potential replacement/expansion.
- Confirmation of existing grit removal equipment capacity with the manufacturer and potential replacement/expansion.
- Expansion of influent wastewater pumps and rebuilding of existing units.
- Improvements to existing influent flow measuring capabilities.

The key decision point for these improvements will be the rate of future population growth as compared to the projections summarized in Chapter 1. Based on the best available information provided by Broomfield, this re-rating will likely be required between the years 2033 and 2035. A detailed alternatives analysis and technology selection was not conducted on the preliminary treatment system in this Utility Plan. To better facilitate future evaluations and conceptual design of preliminary treatment improvements, Broomfield should invest in a full-plant hydraulic model and recording 5-minute influent flow data into SCADA in a way that can be readily exported for engineering analysis.

Capital costs for improvements to preliminary treatment assumed modest hydraulic modifications to increase screening, influent pumping, and grit removal capacity. A detailed hydraulic profile will be necessary to further evaluate preliminary treatment improvements.

3.4.2 Primary Treatment

A detailed alternatives analysis was not conducted on the primary treatment system in this Utility Plan, largely because the existing three units have sufficient capacity for a hydraulic re-rating through the planning horizon based on CDPHE's recommended allowable SOR range. Improvements to primary sludge pumping are warranted both due to equipment age and the need to convey flows to modified solids handling facilities discussed in Chapter 4 – Solids Handling Evaluation.

Note, however, that site space to the north of PC 3 is already allocated for a fourth primary clarifier. Through collaborative planning with Broomfield staff, the project team decided to include construction of the fourth primary clarifier with other near- to mid-term improvements but to use the tank volume as a portion of the facility's new (expanded) flow EQ capacity. This approach is further elaborated upon in the next section.

3.4.3 Flow Equalization

Flow EQ will continue to be an important asset to maintain and likely expand in the future. The secondary treatment system (IFAS zones and secondary clarifiers) and UV disinfection are currently designed assuming an equalized PHF of 18.6 mgd; abandoning flow EQ now would result in costly capital improvements to hydraulically expand unit processes downstream of primary treatment. Furthermore, there likely is not sufficient site space to accommodate such an expansion.

The current EQ tanks are located on the south side of the existing facility in an area that is opportune for constructing and expanding new solids handling facilities in the future (see Chapter 4). Those existing tanks also cannot be further expanded in their current location and are not covered, raising long-term odor control concerns for the BWRF. Through collaborative discussions with Broomfield staff, the project team recommended building a new EQ tank volume immediately to the north of the Administration Building. As noted above, the project team also discussed constructing the fourth primary clarifier to serve as additional EQ volume until Broomfield decides if the fourth unit is ever needed in the future. For this planning effort, the project team assumed a total (future) EQ volume of approximately 2.3 MG (Figure 3.7):

- One rectangular tank sized for approximately 1.5 MG (145 feet long, 90 feet wide, 15 feet SWD). This tank would serve as the day-to-day flow EQ tank for baselining process operations.
- Fourth primary clarifier, sized for approximately 0.8 MG (95 feet diameter, 15 feet SWD). This tank would serve as the secondary EQ tank for buffering a peak wet weather event.

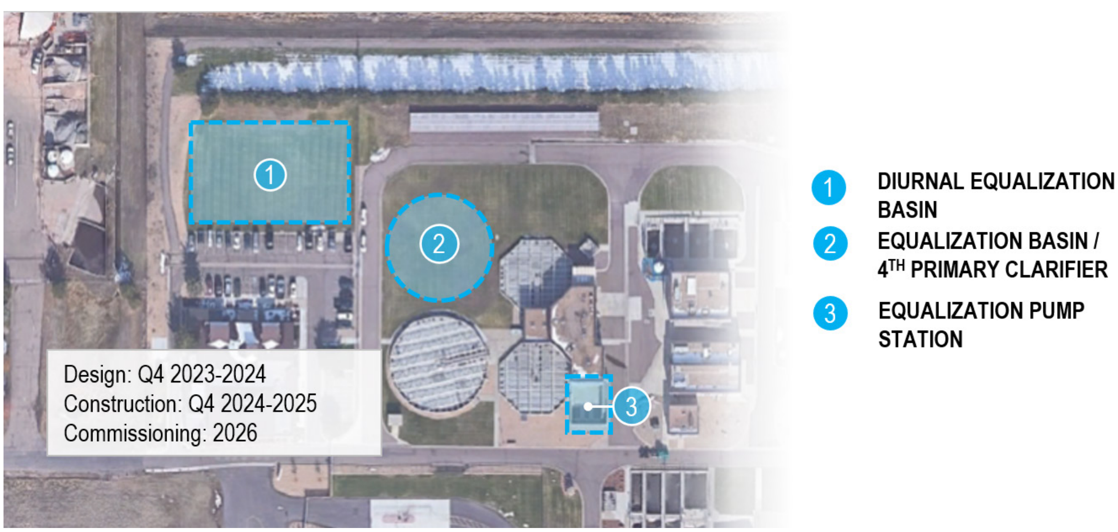


Figure 3.7 Conceptual Layout of New Flow EQ Structures

Assuming the wet weather diurnal flow curve from August 16, 2022 (previously described), an EQ volume of approximately 2.3 MG could theoretically reduce the influent PHF from 36.4 mgd to approximately 21.2 mgd. The project team assumed that this project be grouped with the first phase of improvements in this Utility Plan (i.e., design in 2023/2024 with construction in 2024/2025), as both the future liquid stream treatment expansion and the construction of new solids handling facilities rely on the relocation and expansion of the EQ system.

The cost estimate for new flow EQ, presented in Chapter 7, assumed the following:

- Rectangular EQ Tank:
  - Above-ground concrete structure with architectural exterior veneer or form-liner finish. Structure is assumed to be placed on drilled piers.
  - Mechanical mixing of tank contents.
  - Fiber-reinforced plastic (FRP)/aluminum covers with external trusses. Tank is to be odor controlled.
  - External elevated walkways with handrails (due to height of structure).
- Circular EQ Tank (i.e., fourth primary clarifier):
  - Concrete structure buried approximately 10 feet below grade and placed on drilled piers.
  - FRP/aluminum covers with external trusses. Tank is to be odor controlled.
  - Internal mechanical mechanism (for addition in the future).
- New EQ Pump Station:
  - Consider use of abandoned influent screw pump station wet well to the south of the Old Headworks Building.
  - Could be configured either as a wet/dry well with dry-pit submersible pumps or as a wet well with submersible pumps.
  - A space evaluation of the existing wet well shows that a dry-pit submersible station (Hydraulic Institute 9.8, Figure E.6) and wet well can be located within the existing abandoned wet well footprint.
  - The wet well would be covered for odor mitigation.
  - Further conceptual and preliminary design should be conducted to define desired flow rates, pump type selection, and pipe routing.

3.4.4 Secondary Treatment

Given that the existing secondary treatment system is already an "intensified" process, there is insufficient site space for converting the process back to a traditional activated sludge system. This limits the number of available secondary treatment alternatives to either an IFAS expansion or conversion to another "intensified" process such as the following:

- Membrane bioreactor (MBR).
- NUVODA Mobile Organic Biofilm (MOB)
- Membrane aerated biofilm reactor.
- Ballasted activated sludge (e.g., BioMag®).
- Aerobic granular sludge (AGS) (AquaNereda®).

Based on collaborative brainstorming discussions with Broomfield staff, the general list of intensified secondary treatment alternatives was shortlisted down to an IFAS expansion or conversion to an MBR system. While IFAS expansion is an obvious alternative, the MBR alternative was selected because the project team viewed it as the "least cost alternative" for achieving a similar intensification factor as IFAS without incurring long-term consumable costs (e.g., magnetite for the BioMag® process) and without converting to a sequencing batch reactor style facility (as currently required for the AquaNereda® AGS process).

Note that the NUVODA MOB process was relatively new at the time of the master planning effort, but is gaining increasing attention and market share in the industry. It is recommended that Broomfield keep this technology on the radar as the facility nears a future expansion of the secondary treatment system and potentially evaluate the merits of the process after it is more established. There may be an opportunity to pivot from IFAS to NUVODA relatively easily if the process can meet the capacity requirements of the system long-term.

Table 3.7 summarizes the future discharge goals that were adopted for the BioWin process modeling for compliance with current and upcoming nutrient limits (pre-Regulation 31) at the future ADMMF.

Table 3.7 Proposed Secondary Treatment Goals for Secondary Treatment Process Modeling

Parameter	Future Discharge Requirement	ADMMF Modeling Target	Comment / Justification
TSS (mg/L)	30 (30-day average) 45 (7-day average)	<10	The design should provide sufficient capacity to maintain TSS concentration significantly less than ~20 mg/L. Concentrations above this threshold indicate process upset conditions and can quickly compromise TSS and TP compliance.
BOD_5 (mg/L)	30 (30-day average) 45 (7-day average)	Not of Concern	Even under process upset conditions, BOD_5 compliance is not a concern in BNR facilities.
NH_4 (mg/L)	3.1-5.3 (30-day average) 8.1 to 24 (daily max)	<1	NH_4 concentrations more than 2 mg/L are very difficult to control, indicate approaching nitrification failure, and can easily jump to higher concentrations compromising effluent NH_4 and TIN compliance. Furthermore, revised ammonia stream criteria in coming years will likely result in more stringent daily maximum NH_4 limits.
TIN (mg/L)	14 (daily max) 15 (running annual median) 20 (95th percentile)	<11	This target provides a 20 percent buffer to the daily maximum TIN compliance limit of 14 mg/L. TIN concentrations above this modeled value indicate that external carbon addition will be needed.
TP (mg/L)	1 (running annual median) 2.5 (95^{th} percentile)	<0.8	This target provides a 20 percent buffer to the Regulation 85 running annual median limit. Concentrations above this modeled value indicate that either external carbon or metal salt addition will be needed.

The following design criteria were applied to both the IFAS and MBR evaluations herein:

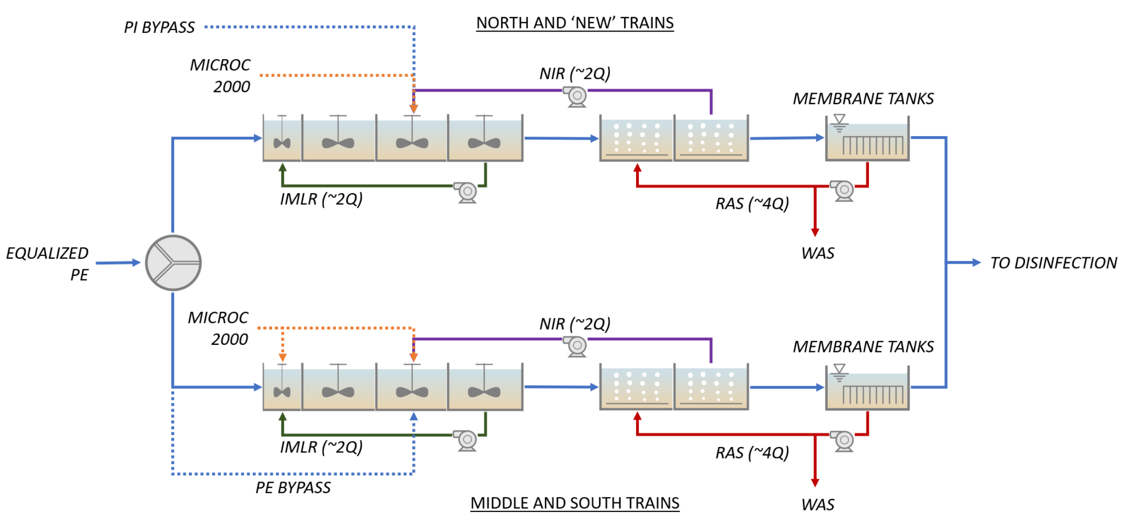
- Wastewater temperature of 13.6 degrees C, which represents the minimum 30-day average temperature since 2018. There is no clear seasonality to peak influent flows and loads consistently overlapping with a particular season and therefore the minimum average wastewater temperature is conservative for capacity planning purposes.
- Primary clarifier TSS and BOD_5 removal efficiency of 60 percent and 32 percent, respectively. Note that these values reflect lower primary clarifier performance than was assumed in the current capacity analysis presented in previous sections and based on long-term operating data from the facility. For conservative planning purposes, the project team estimated future clarifier performance based on SOR when operating the three existing units at 14.0 mgd ADMMF and using criteria established in the WEF's Clarifier Design Manual and 10-State Standards (data graphs not shown).

Additional "technology specific" design criteria targets are highlighted in subsequent sections.

3.4.4.1 Alternative 1 – MBR Expansion

Figure 3.8 provides a simplified process flow diagram of the MBR treatment alternative investigated in this study. This configuration is considered a modified University of Cape Town process, which includes the following IR streams:

- RAS from the membrane tank is diverted to the head of the aerated basins. This returns mixed liquor to the upstream zones while minimizing the potential for oxygen poisoning in the unaerated zones.
- Nitrified mixed liquor is returned from the end of the aerated zone (pre membrane tank) to the head of the anoxic zone for denitrification.
- Denitrified mixed liquor is returned from the end of the anoxic zone to the head of the anaerobic zone for enhanced biological phosphorus removal (EBPR).



Abbreviations
NIR = Nitrate Internal Recycle; IMLR = Internal Mixed Liquor Recycle; RAS = Return Activated Sludge; WAS = Waste Activated Sludge

Figure 3.8 Conceptual Process Flow Diagram of the MBR Alternative

The target design criteria assumed specifically for the MBR process alternative are as follows:

- Maximum membrane tank MLSS of 10,000 mg/L at design ADMMF condition.
- Design aSRT of approximately 8.5 days at a winter wastewater temperature of 13.6 degrees C. This aSRT results in a modeled nitrification safety factor of approximately 1.75 as measured from the point when modeled effluent ammonia exceeds 1 mg/L (aSRT ~4.9 days).
- Maximum organic loading rate of 50 ppd BOD_5 per 1,000 cf of reactor volume.
- Food to biomass ratio between 0.2 and 0.5 lb BOD_5 per lb MLVSS per day.
- DO concentration of 2 mg/L and 4 mg/L in the aeration basins and membrane tanks, respectively.

The benefits and challenges of this alternative are briefly summarized as follows:

- Benefits:
  - Similar "intensification factor" and footprint requirements as the IFAS alternative.
  - Intensification of the existing and new unaerated volume due to operation at higher anaerobic and anoxic biomass inventory.
  - Potential for reducing overall secondary treatment aeration energy requirements as compared to IFAS.
  - No secondary clarifiers are required, allowing for site footprint to be recovered.
  - Improved effluent quality due to membrane barrier process (e.g., low concentrations of TSS, bacteria, particulate phosphorus, and BOD_5).
    - Facilitates high-level disinfection.
    - May minimize expansion of downstream tertiary treatment for non-potable reuse and DPR/IPR.
- Challenges:
  - Higher capital and O&M costs as compared to IFAS.
    - Improved raw wastewater screening will be required at preliminary treatment.
    - Less opportunities to reuse existing tankage and assets during expansion.
    - Increased automation requirements.
  - Higher recycle pumping rates as compared to IFAS, which may result in hydraulic limitations or challenges in the existing infrastructure.
  - Requires an additional IR pump station in the modified University of Cape Town process for achieving low effluent nutrient concentrations and to avoid DO poisoning of unaerated zones.

Process Modeling Results

The MBR alternative was modeled in BioWin at the future design ADMMF, with detailed results presented in Appendix 3D. The steady-state process modeling indicates that to meet the CDPHE recommended design criteria at increased flows and loads, the facility will require expansion of the secondary treatment system to include a fourth train (of equal size to the existing North Train). The fourth secondary treatment train will also provide the necessary redundancy to take a treatment train offline for maintenance during average day conditions. Modeled effluent ammonia, TIN, and TP concentrations were below the effluent limits established in Table 3.7 without the need for external carbon addition.

It is important to note that even with expansion to a fourth treatment train, the unaerated zones at the facility are still smaller than traditional design criteria would recommend for meeting increasingly stringent effluent nutrient limits. Undersized unaerated zones are at greater risk for DO poisoning from IR streams and provide less opportunity for in situ carbon generation via fermentation of particulate carbon and mixed liquor biomass. This is particularly important given the known carbon limitation in the primary effluent. As such, the Carollo team has recommended that with construction of new anaerobic digesters at solids handling, the following improvements be included in the CIP:

- Sidestream nitrogen removal to minimize recycled ammonia loads in the centrate recycle to the liquid stream.
- Sidestream phosphorus to minimize recycled, soluble phosphorus loads in the centrate recycle stream.

Sidestream treatment is discussed in later sections of this chapter (see Section 3.4.7).

Site Layout

The potential site layout for this alternative is shown in Figure 3.9. The fourth secondary treatment train would be constructed in the footprint already reserved for expansion per the existing facility site plan. The new unaerated volume would be constructed to the north side of the North Train unaerated volume, while the aerated volume would be constructed to the south side of the North Train aerated volume. All six secondary clarifiers would be demolished after successful conversion to the MBR process.

For sequencing purposes and given the congesting yard piping currently onsite, it is likely that a dedicated MBR building (membrane tankage plus support equipment) would be constructed for the two north trains and the two south trains, respectively. The MBR building for the north trains could be reasonably constructed in the open space immediately south of SC 5 and SC 6. The MBR building for the South and Middle Trains would likely require construction in the footprint of SC 1 and SC 2. Construction of this MBR building is recommended only after the North MBR system is constructed and online, such that the facility has the ability to operate with three secondary treatment trains at any given time for capacity and redundancy purposes. In this case, the facility would temporarily operate with two MBR trains (North and new volume) plus the Middle Train while the South Train was demolished and converted to an MBR.

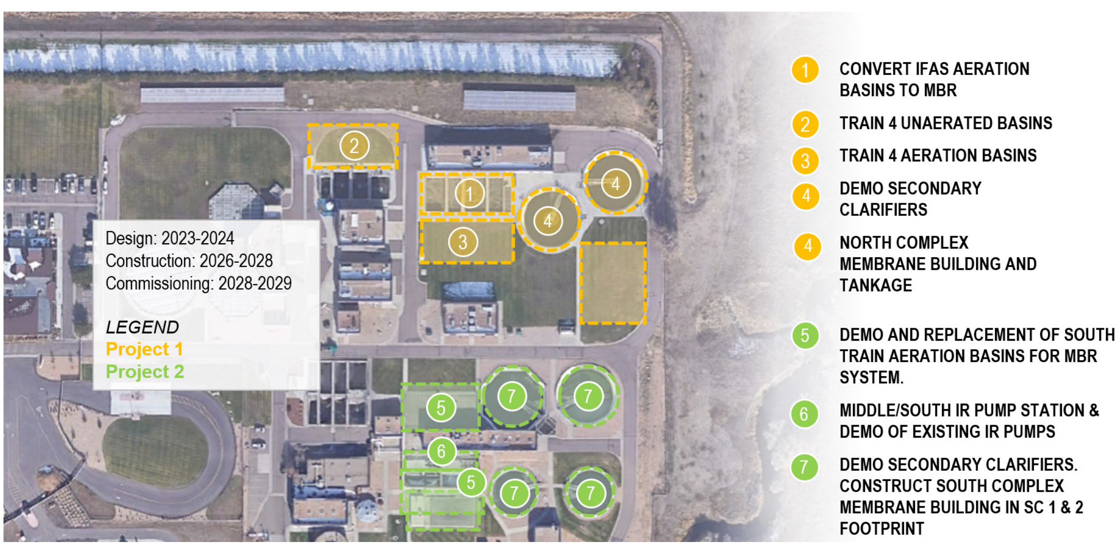
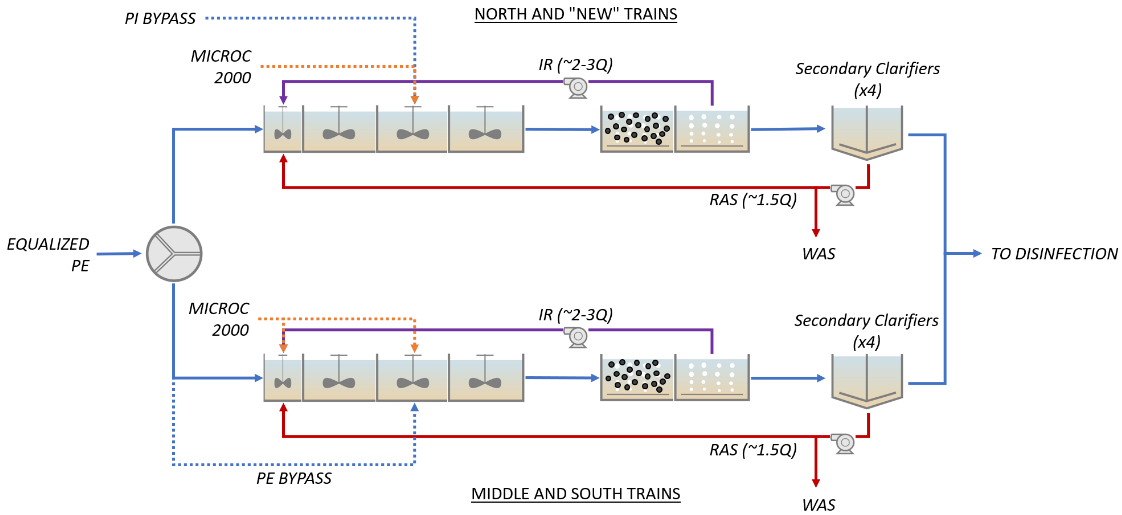


Figure 3.9 Conceptual Site Plan of MBR Alternative at 14.0 mgd ADMMF

3.4.4.2 Alternative 2 – IFAS Expansion

Figure 3.10 provides simplified process flow diagrams of the two IFAS treatment alternatives considered in this Utility Plan. Both options assume treatment expansion of the existing IFAS system; however:

- **Option 1** maintains two IFAS media reactors in each treatment train using the AnoxKaldnes K1 media, operated in series (status-quo). To reduce over-aeration in the second IFAS reactor and to address long-term operational issues noted by Broomfield Staff, Veolia provided the following recommendations:
  - Transfer media from the second IFAS reactor to the first reactor such that the first reactor operates at approximately 45 percent media fill and the second reactor operates at approximately 15 percent media fill. This reduction in fill fraction in the second reactor would require less air for mixing the media and reduce rafting at the sieve wall. This will minimize oxygen recycling in the IR flows and would further reduce carbon demand for denitrification.
  - Modify the air distribution manifold to allow for each drop pipe to control air to the full width of each IFAS basin. This will allow for maximizing aeration under the sieves and for an upstream roll of media (thus minimizing media accumulation at the sieve wall).
  - Add level instrumentation in the IFAS tanks to allow for automated control actions if the water level in the IFAS zones increases (due to media rafting). These actions would include a temporary decrease in the IR flows and temporarily increase in air flows to the IFAS tanks (to reduce media rafting).
- **Option 2** assumes swapping of all K1 media (152.5 square feet per cubic foot [sf/cf]) for K5 media (243.8 sf/cf). In doing so, Veolia states that the all media could be loaded into the first aerated reactor, while the second reactor contains no media and functions as a conventional mixed liquor tank aerated at or below 2 mg/L DO concentration. This option would require the following modifications:
  - In the first IFAS basin (per train):
    - Remove all media and replace with K5 media (at 40 percent fill fraction per Veolia).
    - Remove existing sieves and associated wall supports.
    - Core out existing tank baffle wall holes (or construct new baffle walls entirely) to accommodate new sieves, water level scum screens, and floor screens (to allow for hydraulic EQ across the sieve wall).
    - Install new perforated plate sieves with associated sieve spargers.
    - Modify the air distribution manifold to allow for each drop pipe to control air to the full width of the IFAS tank (as described in Option 1)
    - Add level instrumentation, as described in Option 1).
  - In the second IFAS basin (per train):
    - Remove all media.
    - Remove sieves and associated supports.
    - Install mixers to provide mixing and low airflows and low DO concentrations.



Abbreviations
IR = Internal Recycle; RAS = Return Activated Sludge; WAS = Waste Activated Sludge
Note: IFAS media could be installed in both aerated reactors or in the first aerated reactor only (with replacement of K1 media with K5 media)

Figure 3.10 Conceptual Process Flow Diagram of the IFAS Alternative

Based on discussions with Broomfield and operations staff, Option 2 was the preferred alternative for consideration in this Utility Plan. The target design criteria assumed specifically for the IFAS expansion are as follows:

- Maximum bulk liquid MLSS of 3,500 mg/L.
- Organic loading rate of less than about 1 lb BOD_5 per day per 1,000 sf of media surface area.
- Nitrogen loading rate of less than about 0.3 lb NH_4 per day per 1,000 sf of media surface area.
- DO concentration of 4 mg/L in the IFAS reactors and 2 mg/L in any aerated basins that do not contain IFAS media.

The benefits and challenges of this alternative are briefly summarized as follows:

- Benefits:
  - Strong familiarity with Broomfield staff, with long-standing track record of good treatment performance.
  - Treatment process already exists onsite, with reserved footprint for IFAS expansion in the future.
  - Maximizes use of existing infrastructure that still has remaining useful life (e.g., stainless steel aeration diffusers, aeration blowers, etc.)
- Challenges:
  - High DO concentrations in the last aerated zone have led to oxygen poisoning in the upstream unaerated volumes. This remains a risk in the long term, unless IFAS media and be removed from the second reactor.
  - Media rafting and hydraulic limitations remain a significant concern for operations staff, which must be addressed as part of a future improvements project. This is particularly true in the South Train.

Process Modeling Results

Option 2 of the IFAS alternative was modeled in BioWin at the future design ADMMF and assuming design guidelines recommended by Veolia, with detailed results presented in Appendix 3E. The budgetary quote with recommended design criteria provided by Veolia is provided in Appendix 3F. The steady-state process modeling indicates that to meet the CDPHE recommended design criteria at increased flows and loads, the facility will require expansion of the secondary treatment system to include a fourth train (of equal size of the North Train). The fourth secondary treatment train also provides the necessary redundancy to take a treatment train offline for maintenance during average day conditions. Modeled effluent ammonia, TIN, and TP concentrations were below the effluent limits established in Table 3.7 without the need for external carbon addition.

As previously mentioned, the unaerated zones at the facility are still smaller than traditional design criteria would recommend for meeting increasingly stringent effluent nutrient limits. Undersized unaerated zones are at greater risk for DO poisoning from IR streams and provide less opportunity for in situ carbon generation via fermentation of particulate carbon and the mixed liquor biomass. This is particularly important given the known carbon limitation in the primary effluent. As such, the Carollo team has recommended that with construction of new anaerobic digesters at solids handling, the following improvements should be included in the CIP with the IFAS alternative:

- Sidestream nitrogen removal to minimize recycled ammonia loads in the centrate recycle to the liquid stream.
- Sidestream phosphorus to minimize recycled, soluble phosphorus loads in the centrate recycle stream.

Sidestream treatment is discussed in later sections of this chapter.

Based on the calculated SOR and SLR of the secondary clarifiers with eight units in service (six existing and two new), the units exceed the ADMMF capacity requirements when compared against the CDPHE design guidance in WPC-DR-1. A SPA conducted on the secondary clarifiers indicates that the new and existing clarifiers could potentially handle an equalized PHF between 22 and 29 mgd assuming a MLSS concentration of 3,500 mg/L and an SVI of 150 mL/g (typical BNR facility design value) and 200 mL/g, respectively (using the Daigger and Roper settling curve) (Figure 3.11 and Figure 3.12).

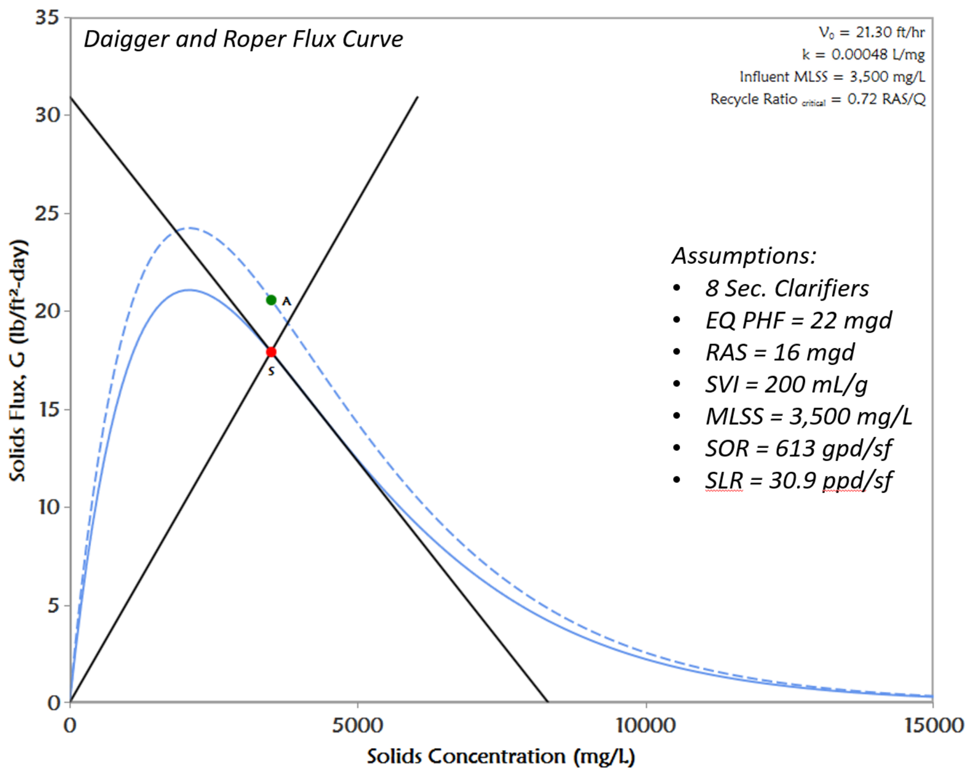


Figure 3.11 SPA for Eight Secondary Clarifiers at EQ PHF of 22 mgd and 200 mL/g SVI

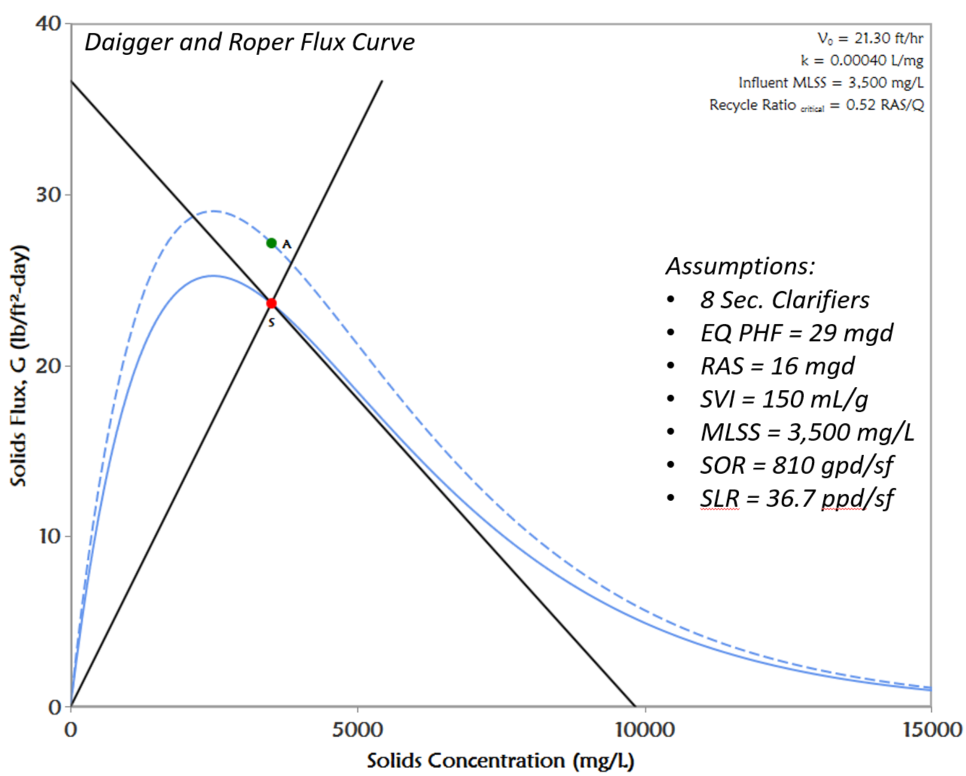


Figure 3.12 SPA for Eight Secondary Clarifiers at EQ PHF of 29 mgd and 150 mL/g SVI

Site Layout

The potential site layout for this alternative is shown in Figure 3.13. The fourth secondary treatment train would be constructed in the footprint already reserved for expansion per the existing facility site plan. The new unaerated volume would be constructed to the north side of the North Train unaerated volume, while the aerated volume would be constructed to the south side of the North Train aerated volume. Two new secondary clarifiers would be constructed for serving the new treatment train.

For sequencing purposes, Carollo recommends that the new treatment train be constructed prior to initiating rehabilitation of any existing IFAS reactors. This is primarily because Broomfield staff have taken the South Train offline due to operational challenges associated with that train.

Figure 3.13 Conceptual Site Plan of IFAS Expansion Alternative at 14.0 mgd ADMMF

3.4.4.3 Selected Secondary Treatment Alternative

The Broomfield staff elected to carry the IFAS alternative forward in this Utility Plan. This is largely since there is a site footprint already reserved for a fourth IFAS treatment train and two additional secondary clarifiers. It was therefore not justifiable to convert the existing system from the IFAS technology to an entirely new MBR process that would likely cost significantly more than the IFAS expansion.

To adequately spread the anticipated capital costs and liquid stream construction burden across multiple years and for overall constructability, Carollo recommends the following secondary treatment expansion approach, with a detailed CIP and project phasing described in Chapter 7.

- **First Step:** Construction of the fourth secondary treatment train and replacement of the existing K1 IFAS media with K5 media in the North and Middle Trains. The driver for this first project would be to increase treatment robustness and redundancy under the current permitted capacity. Construction of the fourth secondary treatment train is required for meeting the current rated capacity of the facility and for sequencing improvements in the existing North and Middle trains assuming that the South Train remains offline until it can be demolished and reconstructed. Based on the current flow and load projections, this project should be under design as soon as possible and online by 2026.

- **Second Step:** Demolition and replacement of the South Train IFAS reactors and two secondary clarifiers. This project should also include demolition and reconstruction of the existing South and Middle Trains IR pump station. The driver for this second project is to provide sufficient liquid stream treatment capacity and redundancy with four operational secondary treatment trains such that the facility could be eligible for a capacity re-rating to meet future flows and loads through the planning horizon (pending capacity expansions at other unit processes like UV disinfection). The key decision point for this second project is projected population growth over the next 3+ years; if current projections come to fruition, then Broomfield may need to deliver these steps simultaneously. This is further discussed in Chapter 7.

Vendor-provided budgetary estimates for the IFAS improvements were obtained from Veolia and included in the capital cost estimates presented in Chapter 7.

3.4.5 UV Disinfection and Effluent Flow Monitoring

Based on the capacity analysis presented above, capital improvements will be required to improve hydraulic conveyance and to increase equipment sizing prior to re-rating the facility beyond 12 mgd ADMMF (31.2 mgd PHF). Two options were considered to increase the capacity of the existing UV system:

1. Expand the existing system (Aquaray® 40 HO) by adding one additional channel which will require expanding the existing building and supporting infrastructure.
2. Replace the existing system with a newer model (Aquaray® 3X) from the same manufacturer that will require modifying the existing channels and weirs to accommodate the new equipment without expanding the existing building.

A comparison of the two different UV systems is shown in Table 3.8. Both systems can treat the future PHF and comply with the design requirements. The Aquaray® 3X system has extra capacity if higher flows are required.

Veolia has provided budgetary estimates for the two different equipment options and are included in the capital cost estimates presented in Chapter 7.

Table 3.8 Comparison of Aquaray® 40 HO and Aquaray® 3X System Configurations

Parameters	Option 1	Option 2
Manufacturer	Veolia	Veolia
Model	Aquaray 40 HO	Aquaray 3X
Configuration		
Number of Channels	4	3
Number of Banks/Channel	3	3
Number of UV Modules/Bank	1	1
Number of Lamps/UV Module	40	36
Total Number of Lamps	**480**	**324**
Number of UV Sensors	12	9
Number of Power Distribution Centers	4	3
Number of Master Control Panels	1	1
Total Power Consumption (kW)	**83.6**	**132.5**

The driver for this project phase is to provide sufficient UV disinfection capacity such that the facility can be re-rated for meeting future flows and loads through the planning horizon. As such, the UV disinfection system should be expanded no later than the second phase of the IFAS secondary treatment expansion.

3.4.6 Reuse Water Treatment Facility

A detailed alternatives analysis and technology selection was not conducted on the RWTF at this time. It was unclear to Broomfield at the time of this Utility Plan what additional reuse capacity the facility may be needed or be available in the future. Therefore, for capital planning and site footprint purposes, a 6 mgd capacity expansion of the RWTF (to total capacity of 12 mgd) was carried forward into Chapter 7. The existing RWTF was assumed to double in size (with same filtration technology) immediately to the west of the existing building.

3.4.7 Sidestream Treatment

As previously noted, a key concern of this liquid stream planning effort is the uncharacteristically low nutrient concentrations in the centrate recycle stream. The historical centrate ammonia concentrations (approximately 100 mg/L to 700 mg/L, average of 389 mg/L since 2016) are low as compared to other Front Range facilities operating anaerobic digesters, where typical concentrations may range from about 600 mg/L to well over 1,200 mg/L. The TP concentrations are also low (about 50 mg/L to 300 mg/L, average of 200 mg/L since 2016) but closer to the expected range for municipal BNR facilities, except for a handful of rapid excursions exceeding 500 mg/L to 800 mg/L. Based on discussions with lab and operations staff, these excursions are likely an artifact of sampling, such as the use of hand-composited grab samples and sampling when the centrifuges were not yet fully seated, resulting in high TSS (and therefore TP) concentration in the sample.

With construction of new anaerobic digesters (Chapter 4), there is risk that these recycle nutrient concentrations (and thereby loads) could more than double. This would further exacerbate the existing carbon limitation and put the facility at increased risk of effluent permit violation – particularly the daily maximum TIN limit. The steady-state model of the expanded treatment facilities (solids and liquids streams) predicts a centrate ammonia and TP concentration of 630 mg/L and 205 mg/L, respectively at design ADMMF. While these concentrations are on the lower end of expected centrate recycle loads from anaerobic digesters, there is enough uncertainty in key historical process data and the subsequent model calibration (each documented in Appendix 3B and Appendix 3C) such that the project team has chosen to conservatively plan for sidestream nitrogen and phosphorous removal.

3.4.7.1 Sidestream Nitrogen Removal

Sidestream ammonia and nitrogen removal technologies are rapidly emerging and maturing in the industry. Figure 3.14 provides a high-level overview of technologies that are at various stages of development or have been implemented by wastewater facilities at full-scale. Based on discussions with Broomfield staff during the Solids Brainstorming workshop in January 2023, the project team quickly narrowed focus to the deammonification (DMX) processes – and particularly, the ANITA™ Mox process offered by Veolia. This centrate treatment technology was shortlisted for the following reasons:

- This technology is offered by the same manufacturer as the liquid stream IFAS system, which offers long-term O&M and equipment coordination efficiencies.
- The operations staff is already familiar with fixed-film processes and is therefore comfortable with the design and operational approach of Veolia's ANITA™ Mox process.
- The system has a proven track record in the United States and in Colorado (currently installed at the Metro Water Recovery's Robert W. Hite Treatment Facility).

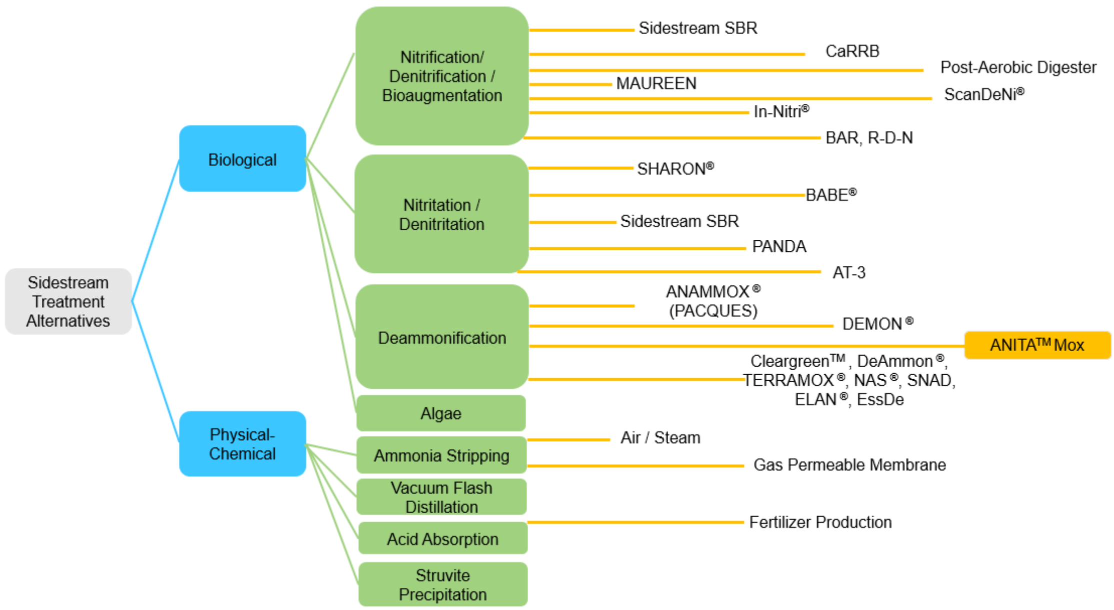


Figure 3.14 Overview of Emerging and Established Sidestream Nitrogen Removal Technologies

Within the ANITA™ Mox process (budgetary cost estimate and recommended design criteria from Veolia provided in Appendix 3G), floating plastic media support a dual-layer biofilm (up to 50 percent fill fraction of reactor volume). On the outer layer of the biofilm, ammonium oxidizing bacteria aerobically convert approximately 50 percent of the centrate load to nitrite. On the inner layer, anammox bacteria (slow growing biomass) use the produced nitrite to anaerobically convert the remaining ammonia to nitrogen gas and a relatively small load of nitrate (simplified nitrogen cycle diagram shown in Figure 3.15). The reactor is aerated to promote biological activity and to keep the reactors well mixed (similar to the liquid stream IFAS system). If unaerated, submersible mechanical mixers can be installed to keep the bulk liquid and media in suspension and well mixed. Sieve screens on the outlet of the reactor retain the biomass-covered plastic media.

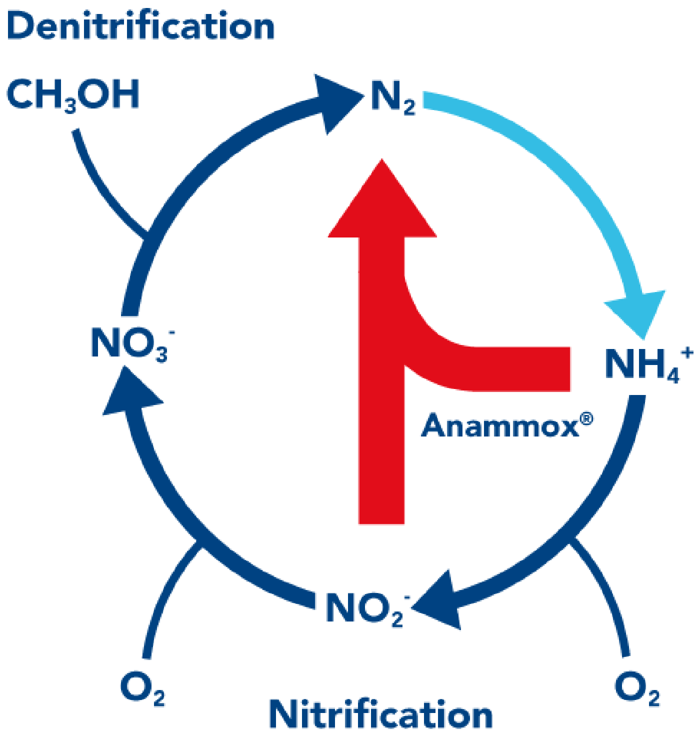


Figure 3.15 Simplified Diagram of Nitrogen Cycle with DMX

The main advantage of DMX processes when compared to conventional nitrification and dentification is a reduction in air, alkalinity, and supplemental carbon, by approximately 65, 50, and up to 100 percent, respectively. The carbon savings is especially important since this facility is already carbon limited in the liquid stream and currently adding external carbon to achieve compliance with an upcoming daily effluent TIN limit.

It is important to note that anammox bacteria require fine-tuned control of the operating conditions to ensure proper nitrogen removal. Alkalinity, DO, pH, ammonia, nitrite, and nitrate are frequently monitored to control the performance. Depending on the alkalinity available in the sidestream, DMX processes typically achieve 80 percent ammonia removal, and 70 to 80 percent TIN removal. Approximately 10 percent of the oxidized ammonia load leaves the reactor as nitrate. These performance criteria were adopted for the BioWin process modeling and then applied to the liquid stream treatment alternatives evaluation.

Although the process is capable of being intermittently fed, these types of systems perform better if they are continuously fed. If dewatering is not performed continuously, as is the case at Broomfield, an EQ tank should be provided between dewatering and the DMX system to allow operational flexibility while maintaining a consistent feed flow rate to the process.

Site footprint for this technology and its supporting tankage and equipment is reserved on the southeastern edge of the site, immediately adjacent to a centrate EQ tank. A key decision point for inclusion of sidestream nitrogen removal will be during conceptual design of the major solids handling improvements (see Chapter 4 and the recommended project sequencing in Chapter 7), during which the design engineer and Broomfield can re-evaluate the need to include sidestream treatment based on:

- Impacts of improved aeration control on denitrification performance in the existing secondary treatment system.
- Estimated external carbon demand required for meeting the daily maximum TIN limit with and without sidestream nitrogen removal.
- Improved process modeling accuracy and resolution, resulting from special sampling of the influent and primary sludge to better characterize the potential centrate nutrient loads resulting from improved VSS reduction in the digestion process.

3.4.7.2 Sidestream Phosphorus Removal

Sidestream phosphorus removal technologies are also rapidly emerging and maturing in the industry. Figure 3.16 provides a high-level overview of technologies that are at various stages of development or have been implemented by wastewater facilities at full-scale. During anaerobic digestion of WAS, most of the phosphorus removed during mainstream EBPR, as well as that from cellular lysis, is re-released into the bulk liquid. The soluble fraction of phosphorus, typically at high concentrations (250 to 500 mg/L), remains in this bulk liquid through solids dewatering and is recycled back to the mainstream process as centrate.

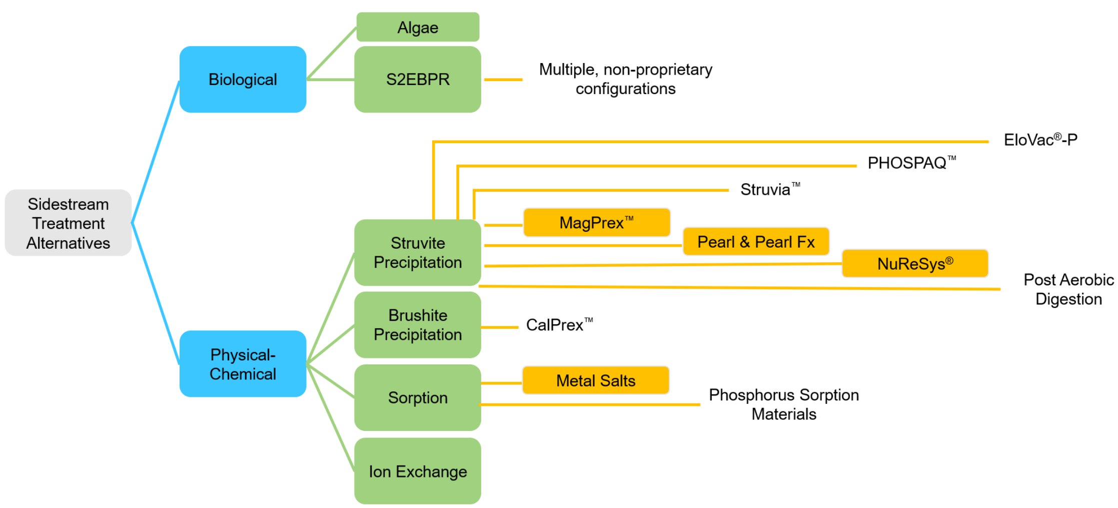


Figure 3.16 Overview of Emerging and Established Sidestream Phosphorus Removal Technologies

This soluble phosphorus load can be challenging to EBPR facilities, particularly because it affects:

- The mainstream phosphorus removal capacity, due in part to increased carbon demand.
- The digested sludge dewatering performance.
- Struvite precipitation across the solids handling processes.

For this study, the project team discussed two options to address soluble phosphorus at solids handling after construction of new anaerobic digesters:

1. **Chemical Precipitation at or Downstream of Digesters:** This approach may require high chemical coagulant doses (i.e., estimated ferric chloride to phosphorus ratio of 1.5:1 to 2.5:1 based on jar testing results from another Front Range facility) and can cause

potential side effects based on anecdotal information obtained from other BNR facilities. (e.g., centrate foaming, pH depression, etc.).

2. **Phosphorus Sequestration and Recovery as Struvite:** This approach involves adoption of a sidestream technology that chemically precipitates orthophosphorus as struvite from digestate or centrate to reduce phosphorus concentrations recycled to the mainstream. Broomfield staff agreed that these technologies should be considered as an add-on process should EBPR be adopted in the mainstream and are further discussed below.

While the main goal was to evaluate the impacts of phosphorus sequestration on mainstream EBPR capacity and carbon availability, the BWRF may also benefit from better control of nuisance struvite formation and improved solids dewaterability. The BWRF may also choose to recover the sequestered phosphorus (a finite resource) for beneficial reuse as a fertilizer and generate a revenue stream.

Leading Phosphorus Removal and Recovery Technologies

At the time of this study, there were three leading providers of phosphorus sequestering technology in the U.S. municipal market:

- Ostara – Pearl®.
- CNP – MapPrex®.
- Schwing Bioset – NuReSys®.

Ostara provides technologies that sequester soluble phosphorus from the centrate, while CNP's MagPrex® technology is integrated upstream of dewatering and treats digested sludge. At the time of this Utility Plan, only the MagPrex® process was operational in Colorado (Metro Water Recovery and Fort Collins Utilities). The NuReSys® system has been marketed by Schwing Bioset to treat centrate, digested sludge, or a combination of both.

Regardless of the target stream, each of these processes capture and precipitate phosphorus as struvite (magnesium ammonium phosphate [$MgNH_4PO_4.6H_2O$]), then exploit the fundamental chemistry of struvite formation (which precipitates at above neutral pH values) to sequester and recover phosphorus in a controlled environment. The captured product has the potential to be used as a fertilizer, presenting the facility with an opportunity to earn a long-term revenue stream. Alternatively, the struvite can be mixed back in with the biosolids and land applied to avoid the additional capital cost and operational complexity of harvesting the product (approach taken at Fort Collins Utilities). An important consideration to note is that all three technologies must be installed upstream of the ANITA™ Mox (or chosen DMX) process as a high ammonia concentration is required to economically drive the struvite formation process.

While a detailed comparative analysis was not completed between these three technologies for this Utility Plan, budgetary proposals were solicited from the three manufacturers and are included in Appendix 3H. Due to recent experience and readily available design and costing information from two local WWTPs, the MagPrex® technology was used for developing budgetary estimates and for process modeling presented in this chapter and in Chapter 7.

Site footprint for this technology and its supporting tankage and equipment is reserved on the southeastern edge of the site, immediately adjacent to the sidestream nitrogen removal system. Based on discussion with Broomfield staff, the key decision point for inclusion of a sidestream phosphorus removal system will be observation of phosphorus recycle loads after the new anaerobic digesters are constructed and operational. Given the influent loading of metal salt residuals from the drinking water facility and the dosing of ferric chloride in the raw influent for odor control, it is not clear at this time if significant phosphorus release will occur in the new digesters or if a large portion of the phosphorus will remain bound to the metal hydroxide sludge leaving with the dewatered cake. Therefore, the near-term approach shall be to provide metal salt dosing capabilities at solids handling and at the liquid stream as backup to for effluent TP compliance until sufficient data can be collected from the new solids handling process. Operations staff may also investigate the use of hydrogen peroxide dosing at the anaerobic digesters to quench hydrogen sulfide demand, which minimizes competition for phosphorus binding to ferric hydroxide sludge in the digesters; this treatment approach has been studied and is currently marketed by PRI-TECH™.

For conservative CIP planning, capital costs for a sidestream treatment process have been included in Chapter 7.

3.5 Liquid Stream Improvements for Forthcoming Regulatory Requirements

The following sections discuss liquid stream improvements that are anticipated for compliance with future effluent temperature limits, Regulation 31 effluent nutrient limits, and PFAS.

3.5.1 Effluent Temperature Compliance

Based on the regulatory review presented in Chapter 1, the facility should plan for temperature limits within the next permit renewal cycle, with implementation occurring sometime in the early 2030s. It should be noted that previous permit renewal cycles generally occurred at regular 5-year intervals; however, renewals have fallen behind from CDPHE, and longer periods between permit renewals frequently occur. Therefore, it is likely that effluent temperature compliance will not be required in the facility's permit until after approximately 2033. Regardless, in case CDPHE does renew the permit on schedule in 2025 and gives Broomfield a 5-year compliance schedule for temperature, the facility should be prepared to pull this project forward such that the limits can be met by 2030.

The BWRF effluent temperature plotted against the MWAT and DM instream temperature standards for the Big Dry Creek were previously shown in Chapter 1. The comparison between effluent temperature and the stream standards indicates that compliance challenges will arise in the winter season for weekly limits (chronic standards). The in-stream standard MWAT for Big Dry Creek is 12.1 degrees C, while effluent temperatures in this time frame are as high as approximately 18.2 degrees C (since January 2019). The DM limits (acute standards) appear to be 5 to 10 degrees C higher than historical effluent temperatures and are therefore not considered herein.

The Fact Sheet to Permit Number CO0026409, dated November 27, 2019, states the following regarding temperature effluent limits: "Temperature: A Water Quality Based Effluent Limit for temperature can only be calculated if there is representative data, in the proper form, to determine what the background MWAT and DM ambient temperatures are. As this data is not available from Broomfield, Westminster, or Northglenn WRFs at this time, the temperature limitation will be set at the water quality standard and will be revisited in the future when representative temperature data becomes available." Since more data are becoming available, it is likely that reductions in winter effluent temperatures will be required as with other Colorado facilities.

3.5.1.1 Initial Overview of Heat Reduction Alternatives

Several effluent temperature reduction options are available for consideration when planning to address future temperature limits at municipal WRFs. These options included alternatives recommended for consideration per the *Methods for Evaluating the Feasibility of Domestic Wastewater Cooling Technology Alternatives* (CDPHE, 2018) as well as other sources. These include:

- Natural heat flow.
- Evaporative cooling technologies.
- Mechanical cooling technologies.
- Innovative or hybrid approaches.
- Source mitigations.
- Liquid and solids stream process changes.

Table 3.9 provides a high-level, initial review of the feasibility of each option with regards to its applicability to the BWRF.

Table 3.9 Overview of Temperature Reduction Technology Options and Initial Feasibility Assessment

Classification	Description	Likelihood of Feasibility
Natural Heat Flow	Heat exchanger using surface water/ shallow groundwater	Likely Infeasible
	Blending using deep groundwater	Likely Infeasible
	Ground loop exchanger/geothermal cooling	Likely Infeasible
Evaporative Cooling	Passive cooling wetlands/pond	Infeasible
	Spray pond	Infeasible
	Once-through cooling tower	Likely Infeasible
Mechanical Cooling	Air-cooled chiller using the vapor-compression refrigeration cycle	**Feasible**
	Chiller with closed-loop cooling tower or other cooling water source	**Feasible**
Innovative, Hybrid, or Combination Approaches	Use of high efficiency motors and energy efficient designs	Infeasible
	Alternate electric sources	Infeasible
	Energy recovery and reuse	<u>Possible as part of a compliance solution</u>
	Adsorption refrigeration	Infeasible
	Electricity from waste heat and other potential advancements	Infeasible
	Reduction in scale of the proposed discharge or activity	<u>Possible as part of a compliance solution assuming DPR/IPR</u>

Classification	Description	Likelihood of Feasibility
Reducing Discharge	Water recycling measures within the facility	Infeasible
	Seasonal or controlled discharge options to minimize discharging during critical water quality periods	Possible as part of a compliance solution assuming DPR/IPR
	Reclaimed water use/land application of wastewater/zero discharge	Possible as part of a compliance solution assuming DPR/IPR
	Process changes, raw material substitution, or alternative technology which could minimize the source of the pollutant	Infeasible
Process Changes	Innovative or alternative methods of treatment and advanced treatment, including new designs, stages, components, capacity for treatment plant replacement or upgrades of current plant	Infeasible
Regulatory/ Political Options	Voluntary or mandatory policies for heat recovery from commercial, retail, or industrial users	Possible as part of a compliance solution
	Site specific standards	Possible as part of a compliance solution

Once through cooling towers have gained significant interest from other Front Range facilities who also face effluent temperature limits. This is generally due to the fact that cooling towers are: 1) a commonly used effluent cooling technology for its simple and reliable operation; 2) the capital cost is relatively low compared to other available temperature mitigation technologies; 3) the fan assembly is the only moving part in the system; 4) the cooling towers can be oversized, enabling the fans to operate at lower speeds for energy conservation; 5) smaller cooling towers can be factory assembled and delivered to the site for installation, while larger units can be constructed onsite; and 6) the system can be expanded in a modular fashion.

As a rule of thumb during initial planning purposes, the ambient mean coincident wet bulb (MCWB) temperature at the BWRF should be at least 5 degrees C lower than the effluent target temperature to make once-through evaporative cooling efficient. The MCWB temperature for Denver (per ASHRAE Climatic Design Conditions) during the month of November ranges from 5 degrees C (at 10 percent cumulative frequency) to 8.3 degrees C (at 0.4 percent cumulative frequency), while the projected effluent WQBEL is 12.1 degrees C. This results in a temperature delta ranging from 3.8 to 7.1 degrees C. Therefore, once-through cooling towers may be a feasible option for meeting standards in the Big Dry Creek (though with little safety factor). If needed, the cooling tower could be coupled with a chiller to ensure compliance with the limit, although it will come at added capital cost and operational complexity and may only be needed for one month out of the year.

A detailed alternatives analysis and technology selection was not conducted for effluent temperature mitigation at this time, beyond the initial feasibility discussion noted above. Carollo recommends that Broomfield initiate a comprehensive wastewater temperature feasibility study in the coming years to analyze options more thoroughly for reducing effluent temperature at the BWRF. This is especially prudent should Broomfield choose to aggressively pursue DPR/IPR in lieu of surface water discharge to the Big Dry Creek or the Great Western Reservoir in the future. For planning purposes, site footprint for once-through cooling towers has been reserved in the southeastern corner of the BWRF. This footprint and the estimated capital costs for construction are presented in Chapter 7.

3.5.2 Regulation 31 Effluent Nutrient Limits

Anticipated future nutrient limits under Regulation 31, *The Basic Standards and Methodologies for Surface Water* (5 CCR 1002 31 Section 31.17), remain uncertain at this time. The interim nutrient values (effective December 31, 2027, if approved by the EPA) for TN and TP limits in warm water streams are 2.01 mg/L and 0.17 mg/L, respectively. However, it is likely that the approved TN and TP limits could be as low as 0.7 mg/L and 0.05 mg/L, respectively, based on the EPA's original recommendations to CDPHE. The 2019 Permit Fact Sheet includes a water quality assessment that defines current low flows and instream concentrations of TP and TN in anticipation of Regulation 31 limits in the coming years. Due to limited assimilative capacity, the calculated effluent limits for the Broomfield, Westminster, and Northglenn facilities are essentially equal to the draft water quality standards in the Big Dry Creek; in other words, the instream criteria would apply as "end-of-pipe" limits for these facilities.

For the liquid stream improvements, compliance with the anticipated Regulation 31 effluent limits at end of pipe would likely require construction of a microfiltration/reverse osmosis system downstream of the secondary clarifiers. Brine disposal from the reverse osmosis system can be a technical and permitting challenge in inland locations like Colorado. To the best of Carollo's knowledge, so-called "zero liquid discharge" systems do not yet exist in full-scale operations in Colorado and stream discharge permitting for brine streams has proven extremely challenging for utilities in the region. Deep well injection, while driving significant capital and O&M costs, has proven to be a viable option in the Front Range for disposal of brine streams in the past; however, this option may be increasingly challenging to permit and could become cost prohibitive in the future. As such, there are now preliminary discussions occurring at the utility, consultant, and regulatory levels about the cost and environmental implications of requiring RO treatment at inland wastewater facilities. For example, the *Life Cycle Assessment of Upgrade Options to Improve Nutrient Removal for the City of Santa Fe, NM, Paseo Real Wastewater Treatment Plant* (EPA, 2023) found that when compared to sidestream and tertiary filtration, reverse osmosis offers the greatest potential for improved nutrient removal but does so at the expense of potentially greater environmental impacts.

Alternatively, Broomfield could consider the option of diverting all effluent flow for reuse rather than discharging to the Big Dry Creek, which at this time would result in less stringent effluent nutrient limits as compared to Regulation 31. This option has water rights challenges and should remain a consideration. As such, the key decision point for Regulation 31 liquid stream improvements will be based on Broomfield's future path towards meeting non-potable and potential potable reuse demands weighed against the effluent nutrient requirements, which are anticipated to be finalized after 2027. It is anticipated that the limits could become effective as annual median limits as early as 2037 assuming 10 years of earned credit under the Voluntary Incentive Program (see Chapter 1).

For the sake of capital planning, Chapter 7 assumes the capital cost and site footprint required for tertiary denitrification filters (limit of technology effluent TN concentration of ~ 2 to 3 mg/L) and tertiary phosphorus removal filters (effluent concentrations of less than 0.1 mg/L achievable, pending recalcitrant concentrations of soluble non-reactive phosphorus). Tertiary filtration technologies were held as part of the CIP at this time in lieu of microfiltration/reverse osmosis/zero liquid discharge largely due to the extraordinary cost increases and the resulting escalation rates anticipated for the next several years. For example, escalation to the midpoint of projects in the year 2037 results in an estimated escalation factor of 80 percent applied to the cost estimates developed for this Utility Plan assuming 2023 dollars. For an RO system in 2037, this results in what is likely an unrealistic projected capital cost to reasonably assume in a 20-year CIP and for which to estimate future wastewater utility rates.

Carollo strongly recommends that Broomfield revisits this recommendation after 2027, once the interim Regulation 31 limits are finalized and all future reuse goals are better defined.

3.5.3 PFAS

While future PFAS regulations for wastewater effluent remain uncertain, it is likely that wastewater treatment facilities will be required to meet water quality standards for discharge to waters designated as drinking water streams and reservoirs. Thus, the most stringent standard the BWRF is likely to face are the proposed PFAS MCLs, including 4 ng/L for each PFOA and PFOS and a hazard index of 1.0 for PFNA, PFBS, PFHxS, and HFPO-DA combined. For tertiary liquid stream treatment from wastewater and reuse plants, granular activated carbon (GAC) or ion exchange (IX) filtration are excellent candidates to remove PFAS at these levels to below the proposed limits. Both technologies employ a media that must be replaced as breakthrough of PFAS compounds occurs. After treatment, these media can currently be sent for landfilling or incineration. It is anticipated that landfilling of PFAS-containing materials will be prohibited in the future. However, incineration of GAC and IX resins is likely an effective technology for media destruction and PFAS mineralization. An important consideration when choosing one of these processes is that total organic carbon will compete with PFAS for pore space; thus, modifications may be needed in upstream processes to reduce TSS and organic carbon as much as possible prior to the media treatment.

While RO can achieve even higher PFAS removals, the technology would result in significantly higher equipment costs and requires an outlet for brine disposal, which may be difficult to find as landfilling is anticipated to become more difficult for PFAS-containing waste streams.

3.6 Odor Control

Odor control remains a critical priority at the facility, which is currently equipped with a comprehensive foul air collection system. Foul air is currently treated by means of a central biofilter that utilizes organic media on which odor oxidizing microorganisms grow and accumulate. Foul air is collected from the following sources:

- Headworks/Screenings Building.
- Grit Building.
- Old Headworks Building.
- Primary clarifiers.
- Headspace of the pre-anoxic zones in the South and Middle Trains.
- Sludge holding tanks.
- Solids Processing Building.

For sake of capital planning, new dedicated odor control systems are assumed for the liquid and solids handling streams, respectively. This is due to the different characteristics and quantities of odors from these sources, as well as site space and layout considerations. The liquid stream odor control system technology is recommended to be a new biotrickling filter constructed in the open space immediately north of PC 1 and PC 2. The solids stream odor control system is recommended to be a carbon adsorption system constructed in the southwest corner of the existing facility. Design efforts for these odor control systems should include odor sampling to verify technology selections.

The site location and reserved footprint for these odor control systems are shown in Chapter 7 along with all cost estimates.

3.7 Summary

The existing liquid stream treatment system has sufficient capacity for meeting current effluent requirements up to the current permitted capacity; however, there is no excess capacity available for re-rating the facility to meet projected growth in Broomfield through the planning horizon. Therefore, phased capital improvements are recommended over the next 20 years to meet growth, increasingly stringent regulatory requirements, and asset rehabilitation needs. Table 3.10 provides a high-level summary of recommended liquid stream improvements and shortlisted alternatives (if applicable) for cost estimating and project sequencing discussed in Chapter 7.

In preparation for the recommended liquid stream improvement projects, Broomfield should consider initiating the following investigations in the coming years. These studies will provide valuable information for preliminary and detailed design efforts.

- **Wastewater and Sludge Characterization – Special Sampling Campaign:** Special sampling of the influent and primary sludge will aid in future process model validation efforts and could better characterize the potential centrate nutrient loads resulting from improved VSS reduction in the digestion process.
- **Comprehensive Wastewater Temperature Feasibility Study**: Analyze viable options more thoroughly for reducing effluent temperature at the BWRF using longer period of available climatic, effluent, and stream temperature data.
- **Hydraulic Profile Development**: Engineering evaluation and development of a full plant hydraulic profile to assess hydraulic limitations and coordinate with upcoming capital projects.

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Table 3.10 Summary of Liquid Stream Improvements Recommended for Utility Plan CIP

Area	Recommended Improvement or Project	Key Driver(s)	Recommended Timing
Preliminary Treatment	Hydraulic capacity and asset improvements in the headworks, screening, and grit removal areas.	Asset Renewal, Hydraulic Capacity	Design (2029-2030), Construction (2031-2032)
Primary Treatment/EQ	Construct diurnal flow EQ basin	Hydraulic Capacity, Site Preparation for Solids Handling Improvements	Design (2023-2024), Construction (2024-2025)
Primary Treatment/EQ	Construct 4th primary clarifier, to serve as additional peak hydraulic EQ for foreseeable future	Hydraulic Capacity, Site Preparation for Solids Handling Improvements	Design (2023-2024), Construction (2024-2025)
Primary Treatment/EQ	Construct EQ pump station	Hydraulic Capacity, Site Preparation for Solids Handling Improvements	Design (2023-2024), Construction (2024-2025)
Secondary Treatment	Construct fourth secondary treatment train (unaerated and aerated volume) for IFAS expansion	Hydraulic and Organic Loading Capacity	Design (2023-2025), Construction (2026-2028)
Secondary Treatment	Construct two new secondary clarifiers for the fourth secondary treatment train	Hydraulic and Organic Loading Capacity	Design (2023-2025), Construction (2026-2028)
Secondary Treatment	Replace IFAS media in North and Middle Trains	Hydraulic and Organic Loading Capacity	Design (2023-2025), Construction (2026-2028)
Secondary Treatment	Demo and replace South Train aeration basins and secondary clarifiers	Hydraulic and Organic Loading Capacity, Asset Renewal	Design (2027-2028), Construction (2029-2030)
Secondary Treatment	Construct new Middle/South IR Pump Station and demo existing IR pumps	Asset Renewal	Design (2027-2028), Construction (2029-2030)
Disinfection	Expansion of existing UV system	Hydraulic Capacity	Design (2027-2028), Construction (2029-2030)
Tertiary	Expansion of existing RWTF by 6 mgd (assumed expansion placeholder)	Recycle Water Capacity Needs in Future	Pending Broomfield Recycle Water Needs
Tertiary	Construction of Regulation 31 technologies for effluent compliance (assumed tertiary denitrification and phosphorus removal filters)	Effluent Nutrient Compliance	Design (2035-2036), Construction (2037-2038) Significant unknowns remain regarding interim nutrient standards and Bromfield's long-term water reuse approach. Revisit closer to year 2027.
Sidestream (Centrate/Digestate)	Construct sidestream nitrogen removal system (ANITA™ Mox assumed herein)	Effluent Nutrient Compliance	Construct with solids handling improvements (see Chapter 4).
Sidestream (Centrate/Digestate)	Construct sidestream phosphorus removal system (MagPrex assumed herein for long-term. Near-term assumes metal salt addition, as needed)	Effluent Nutrient Compliance	Construct after solids handling improvements are completed and if excessively high centrate TP loads are observed. See discussion above.
Odor Control	Construct new, dedicated odor control system for the liquid stream processes	Asset Renewal, Aesthetics	Design (2023-2024), Construction (2024-2025)
Temperature	Construct effluent cooling towers (or similar) for compliance with in-stream temperature standards	Regulations	Design (2029 -2030), Construction (2031 – 2032) May need to be constructed sooner, pending permit renewal cycle and compliance schedule.
PFAS	Construct PFAS treatment technology pending advancement of technologies and regulations	Regulations	Pending regulations

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Chapter 4
SOLIDS HANDLING EVALUATION

4.1 Introduction

This chapter summarizes the solids handling evaluation for the BWRF for the thickening, solids holding, digestion, dewatering, and biogas systems.

4.1.1 Objectives

The solids handling evaluation accomplished the following objectives:

- Evaluate existing solids handling process performance and identify recommendations for improvement aligned with planning and regulatory drivers.
- Conduct high-level review of capital project needs and evaluate potential treatment alternatives.
- Evaluate impacts of changes in the digestion process to dewatering performance, sidestream treatment (further discussed in Chapter 3 – Liquids Stream Evaluation), and biogas production.
- Provide recommendations for use of existing digesters and pre-dewatering storage tanks.
- Consider composting, solids hauling, and resource recovery.

4.1.2 Organization

This chapter is structured as follows:

Section 4.2 summarizes the projected solids values used for understanding future solids handling needs.

Section 4.3 describes the current primary sludge thickening process and recommends a future direction.

Section 4.4 describes the current WAS thickening process and recommends a future direction.

Section 4.5 considers a co-thickening alternative.

Section 4.6 recommends and describes a new pre-digestion blend tank.

Section 4.7 describes the current pre-digestion solids pumps and recommends a future direction.

Section 4.8 describes the current digestion process and recommends a future direction.

Section 4.9 describes the current pre-dewatering solids holding tanks and recommends a future direction.

Section 4.10 describes the current pre-dewatering solids pumps and recommends a future direction.

Section 4.11 describes the current dewatering system and recommends a future direction for the dewatering equipment, solids loadout system, and centrate handling.

Section 4.12 describes the evaluation of two options for beneficially using the biogas, summarizing the relevant financial markets and presenting a capital and life cycle cost analysis, as well as a GHG analysis, for the alternatives.

Section 4.13 provides an overall summary of the solids handing evaluation.

4.1.3 Regulatory Requirements

Current and anticipated regulatory requirements for solids are introduced in Chapter 1 – Basis of Planning. The BWRF currently partially anaerobically digests collected solids then sends the digested solids offsite to be composted to Class A standards. The BWRF would like to improve their digestion process such that it can produce Class B biosolids. While Class A biosolids are a higher quality product that must meet more stringent limits, both Class A and Class B biosolids are subject to Regulation 64 treatment requirements as discussed in Chapter 1. As discussed further in this chapter, Class A requires more treatment and there are limited drivers pushing for the added cost and capacity for beneficial land application in Colorado.

PFAS regulations are a prioritized concern. As detailed in Chapter 1, PFAS are ubiquitously present in solids. While the EPA is working on a risk assessment to determine whether regulation of PFOA and PFOS in solids is appropriate, the CDPHE's WQCD launched a PFAS Interim Strategy via additional Regulation 64 requirements effective as of January 1, 2023. These requirements mandate solids "preparers" like the BWRF whose solids are destined for land application sample and analyze the solids for specified PFAS and then report results to the WQCD. The requirements also identify PFOS as an indicator compound and instruct preparers with PFOS levels greater than or equal to 50 µg/kg to develop and implement a source control program. BWRF analysis of samples from November 2022, December 2022, and January 2023 using EPA Method 1633 yielded PFOS solids concentrations of 17, 14, and 9.8 µg/kg, respectively. The BWRF therefore currently only needs to continue sampling, analyzing, and reporting according to Regulation 64. The progress of the EPA risk assessment and potential future regulations, however, must continue to be tracked. According to the PFAS Strategic Roadmap (EPA, 2021), the risk assessment's targeted release date is 2024. New regulations may impact the feasibility and cost of solids management options by limiting the ability to land apply.

Solids are also subject to CDPHE's Part 20 TENORM rule, effective since January 2021. The requirements of this rule are summarized in Chapter 1. BWRF should continue with characterization as required under 6CCR 1007-1 Part 20 – Registration and Licensing of TENORM.

4.2 Projected Solids Values

Understanding future solids handling needs requires establishing projected solids estimates. As noted in Chapter 1, the planning horizon for this utility plan extends through 2045. The following two approaches were identified to estimate 2045 solids flows and loads:

- Linearly scale current plant-reported solids values to future values.
- Use projected solids values estimated by a BioWin model of the future plant (i.e., one that assumes expansion of the IFAS secondary treatment process). For more information about the BioWin model, see Chapter 3.

The projected solids flows and loads used in this evaluation were ultimately derived from the BioWin model. While the next two sections discuss this decision further, projected ADMM primary sludge and WAS flows and loads were pulled from the model. Projected minimum (taken to equal current ADA), projected ADA, and projected peak 2-week solids values were estimated from the ADMM values, the former two from ratios of different plant influent flow values and the latter by assuming peak 2-week values are 30 percent greater than ADMM values. Table 4.1 outlines these derivations.

Table 4.1 Sources of Projected (2045) Primary Sludge and WAS Flows and Loads

Employed Influent Flows (mgd)			
Design Projected Influent ADA	Design Projected Influent ADMM	1/1/2020 - 8/31/2022 Average Daily Influent	1/1/2020 - 8/31/2022 Influent ADMM
11.5(1)	14.0(1)	6.43(2)	8.15(2)
Sources of Projected Solids Flows and Loads			
Projected ADMM	Projected ADA	Projected Minimum (Estimated as Equal to Current ADA)	Projected Peak 2-Week
From BioWin Model	= Projected ADMM × (11.5 mgd/14.0 mgd)	= Projected ADA × (6.43 mgd/11.5 mgd)	= Projected ADMM × 130%

Notes:
(1) The ADA and ADMM flows in 2045 are predicted to be 10.8 mgd and 13.3 mgd, respectively (see Chapter 1). Slightly higher design values were chosen to be conservative.
(2) From plant-reported data.

Future pre-digestion and digestion solids handling needs were conservatively sized for projected peak 2-week flows and loads. Post-digestion solids handling needs were sized for ADMM flows and loads due to the buffering provided by the long detention times of the digestion process. The projected minimum and ADA values should be considered for unit turndown. While basing these preliminary sizing efforts on peak and maximum values allows for conservative footprint and cost estimates, not only will the units not always experience peak and maximum flows at buildout, but they are currently proposed to be in service well before 2045 (most solids handling improvements are proposed to be operational by 2028 – see Chapter 7 – Recommendations for BWRF Improvements). While beyond the scope of this utility plan, design efforts may need to consider splitting units to allow for adequate turndown.

The next two sections discuss the primary sludge and WAS values utilized in this evaluation in more detail.

4.2.1 Projected Primary Sludge Values

Projected primary sludge values were derived from the BioWin model rather than plant-reported data due to an unresolved discrepancy between current plant-reported values and values estimated via a mass balance performed around the primary clarifiers. As shown in Figure 4.1, the mass balance values are significantly greater than plant-reported values. The plant reported ADMM primary sludge loads for 2020 and 2022 were 12,542 and 8,030 ppd, respectively. The ADMM primary sludge loads calculated via mass balance for 2020 and 2022 were 23,300 and 14,400 ppd, respectively. While the source of this difference is unknown, multiplying the model projected ADMM primary sludge load by the ratio of the current plant influent ADMM flow (8.15 mgd) to the design projected plant influent ADMM flow (14 mgd) calculates a current ADMM primary sludge load of 13,900 ppd. This model-derived value is intermediate to the plant-reported load values and the mass-balance-calculated load values. Model-derived primary sludge flows and loads were therefore chosen for use in solids handling evaluations.

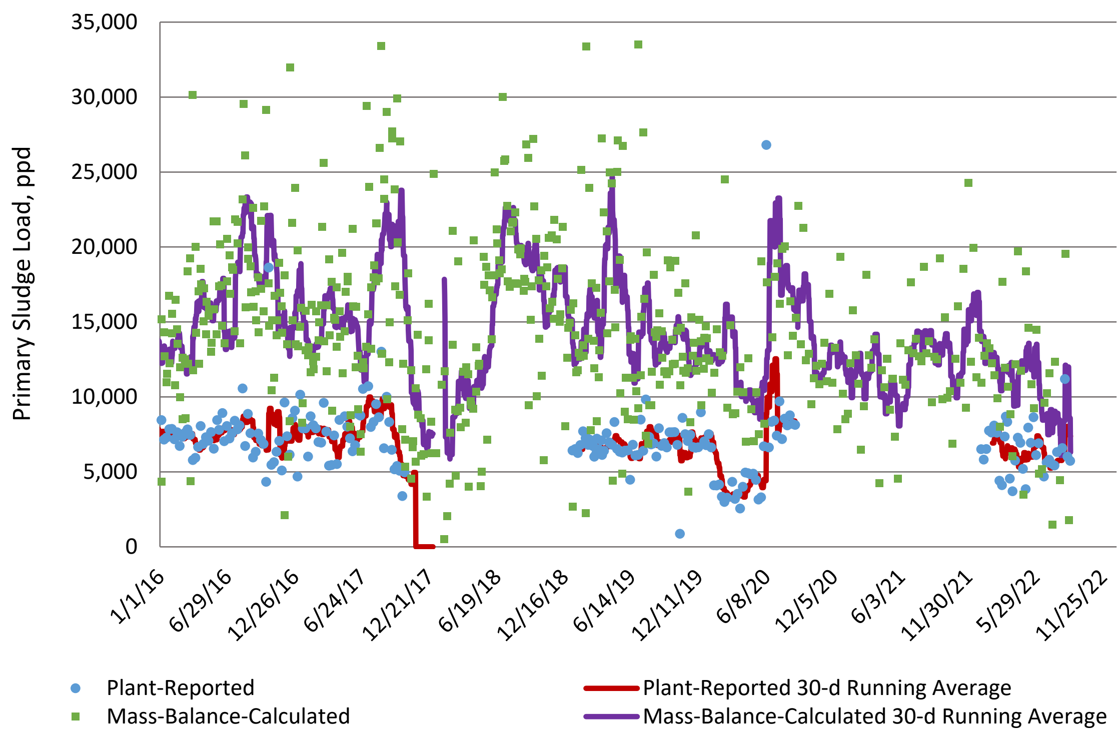


Figure 4.1 Discrepancy Between Current Plant-Reported and Mass-Balance-Calculated Primary Sludge Loads

The model-derived projected primary sludge values are listed in Table 4.2. These values estimate a total solids (TS) concentration of 4.1 percent in the sludge from the primary clarifiers. This value aligns with plant-reported values. The averages of the TS concentrations recorded between January 1, 2020, and August 30, 2022, from PC 1 and PC 2 are 4.11 percent and 3.54 percent, respectively.

Table 4.2 Projected Primary Sludge Values (from Primary Clarifiers)

Parameter	Minimum (Current ADA)	Projected ADA	Projected ADMM	Projected Peak 2-Week
Flow (mgd)	0.032	0.057	0.070	0.091
Load (ppd)	11,000	19,700	24,100	31,300
Concentration (% TS)		4.1(1)		

Notes:
(1) Calculated from listed flows and loads.

4.2.2 Projected WAS Values

Projected WAS values were also derived from the BioWin model rather than plant-reported data (1) due to the absence of plant-reported WAS loads and concentrations and (2) to be consistent in the source of the projected primary sludge and WAS values. Using the model-derived values was preliminarily validated by comparing model-derived loads to loads calculated using RAS concentrations estimated via mass balances performed around the secondary clarifiers. More specifically, multiplying the model projected ADMM WAS load by the ratio of the current plant influent ADMM flow (8.15 mgd) to the design projected plant influent ADMM flow (14 mgd) calculates a current ADMM WAS load of 11,400 ppd. This value is similar to the 2020 to 2022 ADMM WAS loads calculated with estimated RAS concentrations, which range between approximately 9,000 and 9,500 ppd. The model-derived projected WAS values are listed in Table 4.3.

Table 4.3 Projected WAS Values (from Secondary Clarifiers)

Parameter	Minimum (Current ADA)	Projected ADA	Projected ADMM	Projected Peak 2-Week
Flow (mgd)	0.11	0.19	0.23	0.30
Load (ppd)	9,000	16,100	19,700	25,600
Concentration (% TS)	1.0[1]			

Notes:
(1) Calculated from listed flows and loads.

4.2.3 Existing Solids Design Criteria

A summary of current understanding of the BWRF's solids design criteria at the current permitted ADMM flow of 12 mgd and how they compare to CDPHE criteria is included in Table 4.4. Some of the current criteria were formulated with estimated current solids production values.

Table 4.4 Existing Solids Handling Process Design Criteria

Process/Equipment	Unit	CDPHE Design Criteria[1]	Criteria/Capacity
WAS DAFT			
Number of Units	--	--	1
Diameter	feet	--	25[4]
Unit Surface Area	sf	--	491
SWD	feet	10	7.3[4]
SLR at ADMM	pph/sf	Maximum with polymer: 2.0 Maximum without polymer: 1.0	1.7[2]
Anaerobic Digesters			
Number of Units	--	--	3
Diameter	feet	--	Digester 1: 45[4] Digesters 2 and 3: 35[4]
SWD	feet	--	Digester 1: 25[4] Digesters 2 and 3: 19.5[4]
Volume	MG	--	Digester 1: 0.30 Digesters 2 and 3, each: 0.14
Total HRT at ADMM	days	Minimum: 15	4.4[3]
Solids Holding Tanks			
Number of Units	--	--	2
Diameter	feet	--	50[4]
Volume, each	MG	--	0.097[4]

Process/Equipment	Unit	CDPHE Design Criteria(1)	Criteria/Capacity
Solids Overflow Basin			
Volume	MG	--	0.7(4)
Dewatering Centrifuges			
Number of Units	--	--	2
Hydraulic Capacity, each	gpm	--	120-160(4)
Solids Capacity, each	pph	--	1,500-1,800(4)
Centrate Storage Tank			
Volume	MG	--	0.054(4)
Centrate Pumps			
Number of Units	--	--	2
Type	--	--	Recessed impeller centrifugal(4)
Capacity (each)	gpm	--	50-115(4)

Notes:
(1) State of Colorado Design Criteria for Domestic Wastewater Treatment Works (CDPHE, 2022).
(2) Assumes a current ADMM primary sludge load of 13,900 ppd (580 pph), estimated from the BioWin model as described in Section 4.2.1. Value is scaled from the current ADMM influent flow of 8.15 mgd to the existing BWRF design ADMM influent flow of 12 mgd by multiplying by (12 mgd/8.15 mgd).
(3) Assumes a current ADMM primary sludge flow of 0.040 mgd, estimated by multiplying the projected ADMM primary sludge flow of 0.070 mgd from the BioWin model by the ratio of the current ADMM influent flow to the design projected ADMM influent flow (8.15 mgd/14 mgd). Assumes all WAS to the digesters is thickened and uses the 2020-2022 ADMM thickened WAS flow of 0.049 mgd found from plant-reported values. The estimated ADMM total sludge flow to the digesters (0.089 mgd) is scaled from the current ADMM influent flow of 8.15 mgd to the existing BWRF design ADMM influent flow of 12 mgd by multiplying by (12 mgd/8.15 mgd).
(4) Design criteria adopted from Table 4-4 of the 2011 Wastewater Utility Plan Update.
pph pounds per hour
pph/sf pounds per hour per square foot

4.3 Primary Sludge Thickening Evaluation

4.3.1 Current Primary Sludge Thickening

The BWRF does not currently thicken primary sludge beyond what is achieved in the primary clarifiers. Primary sludge is fed directly from the primary clarifiers into the anaerobic digesters. As discussed above, this approach yields a primary sludge TS concentration into the digesters of about 4 percent.

4.3.2 Primary Sludge Thickening Capacity Evaluation

The BWRF may either continue with the current approach of thickening in the primary clarifiers or employ a separate primary sludge thickening system. Implementing additional primary sludge thickening would reduce the hydraulic load on the downstream solids processes. This evaluation considered impacts to downstream solids capacities under both scenarios.

Gravity thickeners, gravity belt thickeners (GBT), thickening centrifuges, and rotary drum thickeners (RDT) are technologies that could be considered to provide primary sludge thickening. Based on discussions with plant staff, gravity thickening was assumed for the potential new thickening system due to comparatively less operational intensity. A gravity thickener would be anticipated to increase the primary sludge TS concentration from 4.1 percent to 7 percent based on data provided by the WEF MOP 8 and Carollo's experience. Gravity thickening is also assumed to be able to achieve a 95 percent solids capture.

Primary sludge can be both fermented and thickened in a unified fermentation and thickening (UFAT) system. The UFAT system is a patented process that operates two tanks in series with the first tank acting as a fermenter (higher sludge blanket) and the second tank acting as a traditional settling tank. The solids and overflow from the first-stage gravity thickener are combined and sent to the second thickener. The fermentation process breaks sludge substrate down into volatile fatty acids (VFA). These VFAs are readily biodegradable and are returned to the secondary process via the gravity thickener overflow, providing an additional carbon source for the BNR process. Generation of up to 500 mg/L VFAs is anticipated in the sidestream of a UFAT system, which equates to approximately 25 mg/L VFAs in the secondary influent. Potential operational impacts of a UFAT system include odor generation and some reduction in biogas production within the anaerobic digestion process due to the diversion of carbon from anaerobic digestion to the secondary process.

As the secondary treatment improvements proposed in Chapter 3 would mitigate the need for external carbon addition, and production of VFAs from primary sludge is not strictly necessary for the process, Carollo does not recommend investing in the significant capital expenditure and footprint required for a second gravity thickener dedicated to fermentation. Carollo's cost estimating team estimates this second tank would cost about $600,000. As mentioned above, a dedicated fermenting tank also has the potential for odor generation that would need to be addressed by additional odor control measures. Instead, Carollo recommends implementing one gravity thickening tank designed to hold a higher sludge blanket. While not a UFAT system, some fermentation could still be accomplished in that tank to generate VFAs for the secondary process if desired. The design phase should consider if this single gravity thickener should be sized slightly bigger than typical to allow for longer solids retention times (SRT). Combining primary sludge flows with TWAS flows (to be discussed below) yields projected peak 2-week total solids flows to the digesters of 0.16 mgd at a 4.1 percent TS concentration without primary thickening and 0.12 mgd at a 5.2 percent TS concentration with primary thickening. To conservatively estimate the needed footprint of potential solids handling units, all post-thickening units were sized assuming primary sludge will not be thickened beyond what is currently achieved in the primary clarifiers. However, the ability to thicken primary sludge can still be implemented, providing the BWRF the option to increase downstream hydraulic capacity if desired. Carollo has proposed a thickening solution that would allow the flexibility to either continue the current approach or thicken primary sludge in a gravity thickener; this system is described below.

4.4 WAS Thickening Evaluation

4.4.1 Current WAS Thickening

The BWRF currently thickens WAS in a single DAFT. There is neither DAFT tankage nor pumping redundancy. As described in Chapter 2 – Facility Assessment, while the existing DAFT is in fair condition, because of its age and lack of redundancy, Carollo recommends constructing a new WAS thickening system. The existing DAFT is also not large enough to treat projected flows and loads.

4.4.2 WAS Thickening Technology Evaluation

In addition to DAFTs, other technologies that can be considered for WAS thickening include GBTs, thickening centrifuges, and RDTs. Mechanical thickeners such as the latter three likely would require a smaller footprint than DAFTs, an important consideration given the space-constrained site. WAS thickening processes should operate continuously as batch wasting could negatively affect both the liquid treatment process and digestion. Since it is recommended staff be onsite during mechanical thickening operations, continuous mechanical thickening would require some level of staffing 24 hours a day and 7 days per week. Continuous staffing is not desirable for BWRF. Staff are satisfied with the performance of the existing DAFT, noting specifically its ease of operation and limited need for chemical addition. As such, continuation of DAFT WAS thickening is recommended, but with new DAFTs that provide redundancy and are sized to handle projected flows and loads.

Carollo proposes the construction of two new DAFTs with one duty unit and one standby unit. One of these DAFTs would be sized larger so it can operate as either a DAFT or a gravity thickener (that can hold a higher-than-typical sludge blanket if desired for fermentation). This setup would offer the BWRF operational flexibility in addition to redundancy. Under normal operation, WAS would be thickened in the duty DAFT, and primary sludge could be gravity thickened in the standby DAFT with the aeration system turned off. When the duty DAFT unit is out of service, the BWRF could thicken primary sludge in the primary clarifiers (i.e., current operation) and use the standby DAFT for WAS thickening as shown in Figure 4.2.

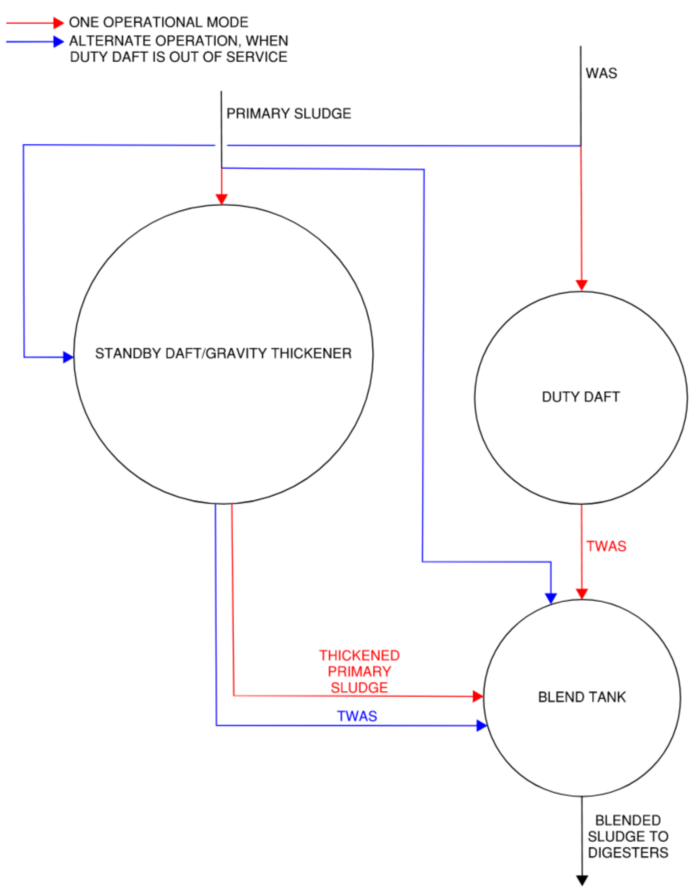


Figure 4.2 Proposed Thickening System Schematic

The proposed thickening tanks were preliminarily sized considering both WAS DAFT sizing criteria and primary sludge gravity thickening sizing criteria. According to *Wastewater Engineering: Treatment and Resource Recovery* (Metcalf and Eddy, 5th Edition), DAFTs thickening WAS should be sized to have a maximum SLR of 2 pph/sf if polymer addition is assumed and a maximum SLR of 0.5 pph/sf if polymer addition is not assumed. CDPHE criteria also require a maximum SLR of 2 pph/sf with polymer addition but allow a higher maximum SLR of 1 pph/sf without polymer addition. Carollo assumed BWRF will add polymer to the new thickening process, allowing for smaller tank sizes on the space-constrained site. While further evaluation and testing would be required to determine the actual extent of needed polymer, the GHG emissions modelling assumes a thickening polymer dosage of 10 lb dry polymer per ton dry TS based on values suggested by *Wastewater Engineering: Treatment and Resource Recovery* and the EPA Gravity Thickening Fact Sheet (2003). It is assumed Broomfield would use the same emulsion polymer currently used for dewatering. That emulsion polymer is estimated to have a 40 percent active chemical content, which translates into a thickening dosage of 25 lb neat emulsion polymer per ton dry TS. To meet a maximum SLR of 2 pph/sf and accommodate projected peak 2-week loads, the duty DAFT would need to be 27 feet in diameter.

According to WEF MOP 8, gravity thickeners thickening primary sludge should be sized to have a maximum SLR of 1.2 pph/sf and a maximum SOR of 760 gpd/sf. These criteria align with CDPHE criteria. To abide by these maximums and accommodate projected peak 2-week flows and loads, the standby DAFT, also meant to operate as a gravity thickener, would need to be 38 feet in diameter. The standby DAFT sizing is governed by which set of criteria – the WAS DAFT criteria or the primary sludge gravity thickening criteria – necessitates the bigger tank size, and it is the latter.

Carollo also proposed the construction of a new DAFT mechanical facility that would house all needed DAFT support equipment and systems, including the recycle/pressurization system, polymer feed system, and solids pumps (see below for further discussion on solids pumps).

Design criteria for the proposed primary sludge and WAS thickening system are presented in Table 4.5.

Table 4.5 Primary Sludge and WAS Thickening Design Criteria

Parameter	Unit	Value
Primary Sludge Thickening		
Operation	--	Gravity Thickener
Number of Units	--	1
Maximum SLR	pph/sf	1.2(1)
Maximum SOR	gpd/sf	760(1)
Diameter	feet	38
Unit Surface Area	sf	1,134
SWD	feet	10(1)
SLR at Projected Peak 2-Week	pph/sf	1.2
SOR at Projected Peak 2-Week	gpd/sf	80
Polymer Dose	lb dry/ton dry TS	10

Parameter	Unit	Value
WAS Thickening		
Operation	--	DAFT
Number of Units	--	2 (1 duty + 1 standby)
Maximum SLR	pph/sf	2.0(1)
Diameter	feet	Duty DAFT: 27 Standby DAFT/Gravity Thickener: 38
Unit Surface Area	sf	Duty DAFT: 573 Standby DAFT/Gravity Thickener: 1,134
SWD	feet	10(1)
SLR at Projected Peak 2-Week	pph/sf	Duty DAFT: 1.9 Standby DAFT/Gravity Thickener: 0.94
Polymer Dose	lb dry/ton dry TS	10

Notes:
(1) In accordance with the State of Colorado Design Criteria for Domestic Wastewater Treatment Works (CDPHE, 2022).

4.5 Co-thickening Evaluation

The option of co-thickening was considered but ultimately not recommended. Carollo has found grit in primary sludge tends to cause major issues in DAFT co-thickening systems. Primary sludge and WAS could alternatively be co-thickened in gravity thickeners, but those tanks would need to be sized for a maximum SLR and SOR of 0.63 pph/sf and 300 gpd/sf, respectively, per CDPHE criteria. To meet those limits, each tank would need a 70-foot diameter. Given the space limitations of the site, the gravity thickener co-thickening option was not deemed to provide sufficient benefit to pursue further.

4.6 Pre-Digestion Solids Holding Evaluation

Carollo proposes the construction of a new post-thickening and pre-digestion blend tank, sized to hold one half day's worth of combined solids. This tank would include mixers, and its primary purpose would be to blend primary sludge and TWAS to ensure a consistent feed to the digesters for optimal digester performance. Sizing the tank for one half day of storage provides a wide spot in the line in case of downstream malfunction while limiting long storage times that would allow the solids to become septic.

Projected solids values to the pre-digestion blend tank are listed in Table 4.6. As noted above, it was assumed gravity thickening could increase the primary sludge TS concentration from 4.1 percent to 7 percent and achieve a 95 percent solids capture. It was assumed DAFT could increase the WAS TS concentration from 1.0 percent to 4 percent based on information from *Wastewater Engineering: Treatment and Resource Recovery* and achieve a 95 percent solids capture. While thickened primary sludge values are listed in Table 4.6, the values that assume no primary sludge thickening were employed to conservatively evaluate and size downstream solids units. Further, as mentioned above, the projected peak 2-week values were used to size all pre-digestion and digestion units.

Table 4.6 Projected Solids to Pre-Digestion Blend Tank

Parameter	Minimum (ADA at Current Flow/Load Values)	Projected ADA	Projected ADMM	Projected Peak 2-Week
Primary Sludge (Not Thickened)				
Flow (mgd)	0.032	0.057	0.070	0.091
Load (ppd)	11,000	19,700	24,100	31,300
Concentration (% TS)	4.1(1)			
Thickened Primary Sludge				
Flow (mgd)	0.018(1)	0.032(1)	0.039(1)	0.051(1)
Load (ppd)	10,400	18,700	22,900	29,800
Concentration (% TS)	7			
TWAS				
Flow (mgd)	0.026(1)	0.046(1)	0.056(1)	0.073(1)
Load (ppd)	8,500	15,300	18,700	24,300
Concentration (% TS)	4			

Notes:
(1) Calculated from other two values (i.e., concentration calculated from flow and load, or flow calculated from load and concentration).

The design criteria for a pre-digestion blend tank sized for projected peak 2-week conditions are presented in Table 4.7.

Table 4.7 Pre-Digestion Blend Tank Design Criteria

Parameter	Unit	Value
Number of Units	--	1
Diameter	feet	25
SWD	feet	23
Freeboard	feet	3
Operating Volume	gallons	84,500
Mixing		Required, type to be determined during design

4.7 Pre-Digestion Solids Pump Evaluation

As outlined in Chapter 2, the current pre-digestion solids pumps have numerous challenges, and their replacement is recommended. This group of pumps includes the primary sludge pumps, the DAFT feed pump, and the TWAS pumps. The current primary sludge pumps are at their end of life. There is only one DAFT feed pump (no redundancy), and it is difficult to access. The current TWAS pumps have redundancy but limited access in their current location in the Maintenance Building. These challenges combined with the proposed relocation of the DAFTs (see Chapter 7) and the need to resize the pumps to handle projected flows culminate in the recommendation to replace them all (adding new pumps for redundancy as needed), as well as relocate the DAFT feed pumps and the TWAS pumps to the proposed new DAFT mechanical facility discussed above. Specific pump type and design conditions will be determined during design development.

4.8 Anaerobic Digestion Evaluation

4.8.1 Projected Flows and Loads

Projected flows and loads to digestion are listed in Table 4.8. Estimated VS loads are included as understanding this fraction of TS is important for digester sizing. These VS loads were derived from the BioWin model and represent about 80 percent of the TS load, a percentage that aligns with typical values.

Table 4.8 Projected Solids to Digesters Values

Parameter	Minimum (ADA at Current Flow/Load Values)	Projected ADA	Projected ADMM	Projected Peak 2-week
Blended Primary Sludge (Not Thickened) + TWAS				
Flow (mgd)	0.058	0.10	0.13	0.16
Load (ppd)	19,500	34,900	42,800	55,700
VS Load (ppd)	15,700[1]	28,100[1]	34,400[1]	44,800[1]
Concentration (% TS)	4.1			
Blended Thickened Primary Sludge + TWAS				
Flow (mgd)	0.044	0.078	0.095	0.12
Load (ppd)	19,000	33,900	41,600	54,100
VS Load (ppd)	15,300[1]	27,300[1]	33,500[1]	43,500[1]
Concentration (% TS)	5.2			

Notes:
(1) VS load estimated as about 80 percent of TS load.

4.8.2 Current Anaerobic Digestion System

As discussed in Chapter 2, the BWRF's anaerobic digestion system requires improvement. All three anaerobic digesters were constructed prior to 1987, with some of the concrete dating to the 1950s. Not only are they structurally at end of life, but the digesters do not accomplish complete anaerobic digestion due to mechanical challenges and inadequate volume. Produced solids are currently treated to Class A standard via third-party composting offsite, but the inhibited digestion process limits the BWRF's ability to capitalize on beneficial biogas and solids reuse opportunities as well as creates dependency on those third parties. The BWRF would like the digestion process to be able to treat the solids to Class B standard. These considerations culminate in the recommendation to construct new digesters capable of fully treating projected loads to Class B standards.

4.8.3 Anaerobic Digestion Design Criteria and Digestion Capacity Evaluation

Anaerobic digestion operational modes the BWRF could choose to implement with the new digesters include conventional mesophilic digestion, two-phase digestion, and temperature-phase anaerobic digestion (TPAD). Conventional mesophilic digestion involves digesters operating in parallel at around 95 to 98 degrees Fahrenheit (F) and is capable of meeting Class B standards. Two-phase digestion separates the acid and methane formation steps of anaerobic digestion into separate tanks. Each tank is uniquely designed and operated to create an environment with the most favorable growth conditions for its specific bacteria (acidic for the acid-producing bacteria and neutral-pH for the methane-producing bacteria). All solids would enter the acid-phase digester(s), which would be sized for a 2- to 3-day HRT. Partially digested solids would then flow to the methane-phase digester(s), which would be sized for at least a 12-day HRT. Two-phase digestion can increase gas production and reduce foaming potential as compared to conventional mesophilic digestion. TPAD, where digestion is operated at thermophilic temperatures (above 122 degrees F) in the first phase and at mesophilic temperatures in the second phase, can meet Class A standards if the thermophilic phase is operated as a batch process. The thermophilic conditions enhance reaction rates and pathogen reduction (enabling Class A standard) but have a higher heating energy demand.

While the phased digestion modes can optimize treatment by catering to the different anaerobic digestion steps and allowing the implementation of a thermophilic stage, they are more complex to operate and maintain. Given one of their key advantages, the ability to treat to Class A standard, is not required for BWRF, Carollo recommends proceeding with conventional mesophilic digestion.

Four new anaerobic digesters are recommended – two active digesters, one redundant digester, and one secondary digester to provide pre-dewatering solids storage (discussed further below). The digesters were preliminarily sized to handle projected peak 2-week flows and loads according to the following CDPHE design criteria for single-stage mesophilic anaerobic digestion processes:

- Maximum VS loading of 0.20 ppd/cf.
- Minimum HRT of 15 days.

These design criteria are consistent with Class B pathogen reduction requirements (minimum HRT of 15 days at a temperature between 95 degrees F and 131 degrees F).

To meet those design criteria and assuming two active digesters, each digester was sized to have a 71-foot diameter, a 43-foot SWD, and a 46-foot full wall depth (assuming at least 3 feet of freeboard provided). These dimensions assume a 3:5 SWD to diameter ratio as is typical for conventional "pancake" style digesters. More innovative digester shapes (e.g., silo style) with more efficient footprints could be considered in the design phase. This high-level evaluation assumes the conventional style to be conservative with footprint planning. Design criteria for the anaerobic digesters are presented in Table 4.9.

Table 4.9 Anaerobic Digester Design Criteria

Parameter	Unit	Value
Number of Units	--	4 (2 duty + 1 standby + 1 pre-dewatering storage)
Minimum HRT	days	15[(1)]
Maximum VS Loading	ppd/cf	0.20[(1)]
Diameter	feet	71
SWD	feet	43
Freeboard	feet	3
Operating Volume, each	gallons	1,260,000

Parameter	Unit	Value
HRT at Peak 2-Week without Primary Sludge Thickening	days	15
HRT at Peak 2-Week with Primary Sludge Thickening	days	20
VS Loading at Peak 2-Week without Primary Sludge Thickening	lb VSS/cfd	0.13
VS Loading at Peak 2-Week with Primary Sludge Thickening	lb VSS/cfd	0.13

Notes:
(1) In accordance with the State of Colorado Design Criteria for Domestic Wastewater Treatment Works (CDPHE, 2022).
lb VSS/cfd pounds of volatile suspended solids per cubic feet per day

Sizing the digesters according to projected peak 2-week flows and loads and only two active digesters offers the BWRF sufficient capacity for operational flexibility and security against unexpected events. Operating two digesters at projected ADA and ADMM flows provides HRTs of 25 days and 20 days, respectively, well in exceedance of the 15-day minimum. If three digesters are active, those HRT values increase to 37 days, 30 days, and 23 days for projected ADA, ADMM, and peak 2-week flows, respectively. If four digesters are active, those HRT values become 49 days, 40 days, and 31 days, respectively.

To be footprint efficient, Carollo proposes building these four digesters in a quadrangle with a building integrated in the space between them to house needed ancillary equipment such as digester heating equipment (e.g., boilers, heat exchangers, hot water pumps, etc.) and dewatering feed pumps.

4.9 Pre-Dewatering Solids Holding Evaluation

4.9.1 Current Pre-Dewatering Solids Holding

Pre-dewatering solids are currently stored in two 50-foot diameter SHTs, each with a 0.097-MG capacity. Partially digested solids are stored in SHT 1 and WAS and TWAS that bypass digestion are stored in SHT 2. Overflow from SHT 1 is stored in a 0.7-MG concrete basin with a floating cover on the south side of the site. As discussed in Chapter 2, the two SHTs are approaching their end of life, and as shown in Chapter 7, their current location eventually may be needed for future treatment processes like tertiary filters and PFAS technology. As discussed in Chapter 7, the overflow basin will need to be demolished to create space for other solids handling improvements. It is therefore recommended to provide pre-dewatering solids holding in a new location.

4.9.2 New Pre-Dewatering Solids Holding Evaluation

Carollo recommends using one of the four tanks within the new digestion complex (described above) for pre-dewatering solids holding. The tank can be designed to handle variable volumes with mixing to provide a consistent feed to dewatering. The tank can also be designed to be heated, allowing it to operate as backup digestion volume.

With an operating volume of 1,260,000 gallons, this pre-dewatering solids holding tank would provide about 10 days' worth of solids storage at projected ADMMF. It is generally recommended to provide enough storage to hold solids over a long weekend. This solution provides more than the recommended amount while also providing redundancy for digester operation.

Projected digested solids values are listed in Table 4.10. The listed load values assume a volatile solids reduction (VSR) of 36 percent over the course of digestion. This percentage was taken from the BioWin model and is not only lower than typical for anaerobic digestion but likely lower than what the BWRF would experience in new digesters. The volatility of the influent residuals from the drinking water treatment plant is unknown, and this analysis assumes they are all inert (i.e., that they do not degrade during digestion). This assumption is conservative; the lower the VSR, the higher the amount of solids sent to dewatering, and the lower the amount of biogas generated that can be beneficially used. However, it is unlikely all the residuals are inert, and when the drinking water residual solids load is removed from the VS load in the BioWin model, the digester VSR becomes 47 percent (a more typical value). The drinking water residuals should be better characterized after progressing into design.

Table 4.10 Projected Digested Solids Values

Parameter	Minimum (ADA at Current Flow/Load Values)	Projected ADA	Projected ADMM	Projected Peak 2-Week
Digested Primary Sludge (Not Thickened) + TWAS				
Flow (mgd)	0.058	0.10	0.13	0.16
Load (ppd)	13,900(1)	24,800(1)	30,400(1)	39,600(1)
Concentration (% TS)	2.9			
Digested Thickened Primary Sludge + TWAS				
Flow (mgd)	0.044	0.078	0.095	0.12
Load (ppd)	13,500(1)	24,100(1)	29,600(1)	38,500(1)
Concentration (% TS)	3.7			

Notes:
(1) Assumes 36 percent VSR in the digesters (percentage from BioWin model).

4.10 Pre-Dewatering Solids Pump Evaluation

As discussed in Chapter 2, the current pre-dewatering solids pumps are in poor condition, and as described in Chapter 7, the waste sludge pump station they are located in needs to be demolished to make space for tertiary filtration and PFAS treatment systems. As such, it is recommended these pumps be replaced and relocated in the new digester complex (i.e., the support building integrated between the four digesters). Specific pump type and design conditions will be determined during design development.

4.11 Solids Dewatering Evaluation

The current solids dewatering system is located in the Solids Processing Building and is comprised of two dewatering centrifuges with polymer feed and screw conveyors, a truck loadout, and centrate holding and pumping. Each one of these components is evaluated below.

4.11.1 Dewatering Centrifuge Evaluation

While current dewatering performance is good, the existing centrifuges have capacity limitations and are nearing their end of life. As such, they are recommended to be replaced. The BWRF could install either two or three centrifuges that provide the upsized capacity required to meet projected flows and loads. Carollo preliminarily proposes two upsized centrifuges to reduce impacts to the existing structure (which is in overall good condition). If the two upsized centrifuges can fit in the location of the two current centrifuges, only the screw conveyors and centrifuge platforms (to accommodate larger centrifuges) would need to be replaced. If three new centrifuges are selected, not only would the current aging screw conveyors and potentially the centrifuge platforms need to be replaced, but installation of and access to a third conveyor and platform would need to be accommodated. While preliminary information provided by one manufacturer (Centrisys) suggests two upsized centrifuges would fit in the current Centrifuge Room, the design phase should include confirmation with more refined manufacturer-provided footprints.

Projected solids to dewatering values are listed in Table 4.11. These values have been adjusted from Table 4.10 to account for a dewatering operation schedule of 6 days per week and 10 hours per day (matches the current operation schedule). When a centrifuge is selected to accommodate these flows and loads, it is recommended to consider the projected ADMM values and to derate the centrifuges to approximately 70 percent of the manufacturer-listed capacities. Carollo recommends derating centrifuges from manufacturer-claimed values based on operational input from other facilities to ensure and maintain desired performance (especially with biological phosphorus removal in the liquids treatment process, which reduces solids dewaterability).

Table 4.11 Projected Solids to Dewatering Values Considering Operation Schedule(1)

Parameter	Minimum (ADA at Current Flow/Load Values)	Projected ADA	Projected ADMM
Without Primary Sludge Thickening			
Flow (gpm)	112	200	245
Load (pph)	1,600	2,900	3,600
Concentration (% TS)		2.9	
With Primary Sludge Thickening			
Flow (gpm)	85	151	185
Load (pph)	1,600	2,800	3,500
Concentration (% TS)		3.7	

Notes:
(1) Assumes continuation of current dewatering operation schedule of 6 days per week and 10 hours per day.

Design criteria for upsized centrifuges are provided in Table 4.12.

Table 4.12 Centrifuge Design Criteria

Parameter	Unit	Value
Operating Days per Week	days	6
Operating Hours per Day	hours	10
Number of Units	--	2 (1 duty + 1 standby)
Hydraulic Capacity, each	gpm	315(1)
Solids Capacity, each	pph	3,500(1)

Notes:
(1) Values are manufacturer-claimed, example values derated by 30 percent.

Projected dewatered solids values are listed in Table 4.13. It was assumed the new centrifuges could achieve a 95 percent solids capture and a 22 percent TS concentration (from *Wastewater Engineering: Treatment and Resource Recovery*) with a wet cake density of 55 pounds per cubic foot. This is comparable to current dewatering performance, although changes in solids handling and digestion may affect dewaterability.

Table 4.13 Projected Dewatered Solids Values[1]

Parameter	Minimum (ADA at Current Flow/Load Values)	Projected ADA	Projected ADMM
Without Primary Sludge Thickening			
Flow (mgd)	0.0084	0.015	0.018
Load (ppd)	15,400	27,500	33,700
Concentration (% TS)		22	
Volumetric Flow (yd^3/d)	47	84	103
With Primary Sludge Thickening			
Flow (mgd)	0.0082	0.015	0.018
Load (ppd)	14,900	26,700	32,800
Concentration (%TS)		22	
Volumetric Flow (yd^3/d)	46	82	100

Notes:
(1) Assumes current dewatering operating schedule of 6 days per week and 10 hours per day. Each daily value is "per operating day."
yd^3/d cubic yards per day

Projected centrate flows are listed in Table 4.14. These flows assume dewatering is operational.

Table 4.14 Projected Centrate Flows Assuming Operational Dewatering

Parameter	Minimum (ADA at Current Flow/Load Values)	Projected ADA	Projected ADMM
Without Primary Sludge Thickening			
Flow (gpd)	58,700	105,000	128,800
With Primary Sludge Thickening			
Flow (gpd)	42,600	76,200	93,400

4.11.2 Dewatered Solids Loadout Evaluation

The current solids loadout system directly discharges dewatered solids produced by the centrifuges into a truck trailer via screw conveyors. The BWRF must pay to lease the trailer while it is being filled and must stop dewatering operations when it is full to allow the trailer to be moved and replaced. This system is functional but has operational costs and limitations.

The BWRF desires the installation of either hoppers or silos to store solids between the centrifuges and the loadout trucks. The hoppers/silos would be installed directly underneath the centrifuge conveyor discharge chutes such that stored solids could be directly discharged into loadout trucks parked underneath. This improvement would minimize the lease time of the trailers (the trailers would only be used for loading and not also storage) and enable continued solids processing while trucks are full and moving.

Initial preferences from BWRF staff would be to have 7 days of dewatered solids storage, which is a conservative amount. Based on the projected ADMM dewatered solids values listed in Table 4.13, the hoppers/silos would need to be able to hold 620 cubic yards. The Solids Processing Building would likely require a new truck bay and conveyor platform positioned further from the centrifuges to allow appropriately sloped conveyance to the new hoppers/silos. Future design efforts should identify an appropriate storage volume, location, and conveyance approach.

4.11.3 Centrate Storage Evaluation

As outlined in Chapter 2, current centrate storage is insufficient for process needs, and this limitation will be exacerbated as flows increase to projected values. Additional centrate storage will also become more critical when the new digesters come online. Anticipated improved digester performance will increase nutrient recycle loads, and providing adequate storage to better control centrate return to the liquid treatment process will be necessary to maintain liquid process capacity. Centrate (sidestream) treatment will also be necessary, as discussed in Chapter 3.

Carollo proposes constructing a new centrate storage tank to be located outside the Solids Processing Building and adjacent to the new sidestream treatment systems the centrate will need to feed into. It is recommended to design this tank such that it is split into two equal cells to provide BWRF staff the operational flexibility to perform maintenance on one cell and still have the other cell available for centrate storage. Design criteria for this tank are provided in Table 4.15.

Table 4.15 Centrate Storage Tank Design Criteria

Parameter	Unit	Value
Number of Tanks	--	1
Number of Cells per Tank	--	2
Required Storage	days	3
Required Tank Volume	MG	0.39
Tank Length	feet	70
Tank Width	feet	35
Tank SWD	feet	21
Freeboard	feet	3

It is recommended to maintain the current centrate storage tank in the Solids Processing Building for additional capacity, and to feed the new centrate storage tank from this existing one. However, as noted in Chapter 2, the current centrate pumps wear out quickly, and the centrate lines have a history of clogging and are difficult to clean without cleanouts. New centrate pumps and distribution piping are recommended to convey centrate from the current tank to the new tank.

4.11.3.1 Struvite Mitigation

As noted above, once the BWRF transitions to full anaerobic digestion, increased levels of nutrients will end up in the centrate stream where they will increase the potential for struvite precipitation. Struvite is a hard, crystalline precipitate made of magnesium, ammonia, and phosphate ($NH_4MgPO_4 \cdot 6H_2O$) that can form in piping and equipment within and downstream of anaerobic digesters. Therefore, the new digesters and centrate system should be designed to minimize struvite formation. All potential struvite control measures involve adjusting the conditions of the process flow to increase solubility, including:

- Reducing the concentrations of one or more of the constituents that make up struvite through either precipitation or metal substitution.
- Controlling environmental conditions, i.e., decreasing the pH, increasing the temperature.
- Preventing struvite formation potential by using certain pipe materials and coatings.

Sidestream treatment of centrate, as discussed in Chapter 3, can sufficiently reduce phosphorus concentrations to inhibit struvite precipitation.

Addition of an acidic chemical, such as ferrous chloride, ferric chloride, and alum can be used to decrease the pH. However, this addition is typically done downstream of anaerobic digestion due to the desire for the mesophilic bacteria to remain at a neutral pH. There are a few other chemical techniques that can be implemented instead of pH modification, such as crystal inhibitor polymers and scavenger polymers that prevent crystal nucleation. Several chemicals are also available to clean struvite scale from pipes, heat exchangers, valves, etc. (Struv-Free ST-Dur2520 supplied by Guard Products and Struvite Remover STSR supplied by Jayne Products). As such, Carollo recommends including provisions for chemical recirculation to control struvite formation in the design of the new digesters and centrate system.

Selecting an appropriate pipe and pipe lining material is an important way to decrease struvite formation in piping systems. Generally, the smoother either the pipe material or lining, the less opportunity for struvite buildup. Clean Water Services in Oregon tested different piping materials at their Durham Water Resource Recovery Facility to assess struvite scaling. Specifically, they looked at rubber, polypropylene, Teflon™, polyvinylidene fluoride (Kynar®), and polyvinyl chloride (PVC). Of these materials tested, PVC and butyl rubber fared the worst while the Kynar® did the best, with no struvite accumulation. WRFs across the country typically use glass-lined ductile iron pipe (DIP) on sludge and centrate piping with success. Metro Water Recovery (formerly Metro Wastewater Reclamation District) tested Kynar®-lined DIP with good results. However, Kynar® is expensive and has limited installations. Furthermore, based on feedback from contractors, Kynar® is difficult to work with as it is not amenable for field modifications and requires a special fusion machine to fabricate and install the pipe.

To reduce the formation of struvite, the following design strategies are recommended:

- Minimize turbulence in piping systems by reducing the number of elbows, reducers, and valves to the extent possible.
- Use either 45-degree bends or long radius elbows wherever possible rather than standard radius 90-degree elbows.
- Install isolation valves and camlock flushing and drain connections to allow for chemical recirculation, especially on the upstream and downstream sides of pumps and heat exchangers.
- Locate pressure gauges upstream and downstream of piping and heat exchangers to monitor pressure buildup.
- Provide accessibility into piping systems for maintenance, such as with dismantling joints.
- Consider installation of electric pulse technology, such as HydroFLOW, on exposed piping systems. HydroFLOW devices induce a 150 kilohertz, oscillating sine wave,

alternating current signal. This signal is believed to cause the mineral ions that make up struvite to form loosely held together clusters that remain in suspension. HydroFLOW has been shown to limit struvite precipitation to a length of approximately 50 feet downstream of the unit.

4.11.4 Dewatered Biosolids Beneficial Use

Dewatered biosolids are currently hauled offsite to a private composter that treats them to Class A standard prior to land application at Broomfield's resource recovery farm near Gilcrest. While it is assumed third-party composting will continue in the near term, staff would like to lessen the risk inherent to relying on a third party.

Treatment to Class A standard is notably not required for land application. Class B land application sites must meet the criteria specified in Section 64.15 of CDPHE Regulation 64. There are limits on a land application site's proximity to surface water, the depth to groundwater in the vicinity of the site, topography (slope), its soil quality, and what crops are grown on the site. The total area of land required for biosolids application varies substantially based on the nitrogen content of the biosolids and the nitrogen uptake rate of the crops or vegetation on the site. Biosolids loading rates for dryland and irrigated sites are as follows:

- Dryland biosolids application rates range from 2 to 3 dry tons/acre.
- Irrigated application rates range from 7 to 10 dry tons/acre.

Broomfield's current farm has 1,364 acres but only about 1,000 acres are irrigated with some dry land farming. The projected annual average biosolids production of 27,500 lb/operating day (Table 4.13, without primary sludge thickening) translates to 14 dry tons/operating day and 4,400 dry tons/year. Using the application rate estimates provided above, Broomfield would need up to 2,200 acres for land application on dry land and 630 acres for application on irrigated land assuming just one crop cycle application per year. Based on the available irrigated acres, the current farm has sufficient capacity for Class B biosolids land application through 2045.

Given the current lack of either regulatory or financial incentive to treat to Class A, it was decided with plant staff to only treat to Class B standard at the BWRF. These Class B biosolids could be land applied at Broomfield's resource recovery farm if the BWRF decides to move away from third-party composting. If drivers shift in the future to favor Class A production at the BWRF, potential post-dewatering technologies that could be implemented include composting, heat and solar drying, heat treatment, thermal aerobic digestion, pasteurization, and others demonstrated and approved by the EPA. Drying technology could be coupled with a future PFAS treatment technology such as gasification or pyrolysis.

4.12 Beneficial Biogas Use Evaluation

The BWRF currently flares all produced biogas. Environmental, social (i.e., public perception), and financial incentives combine to encourage the BWRF to implement a beneficial biogas use system. Importantly, Broomfield adopted Resolution 2020-169 that set ambitious GHG emission reduction goals and asked Broomfield organizations such as the BWRF to reduce their GHG emissions by 100 percent by 2050. Capturing and beneficially using the biogas instead of flaring it would be a necessary step toward this achievement. Potential beneficial use options are explored and described in the following sections.

4.12.1 Biogas Production Evaluation

The amount of biogas the BWRF produces will increase not only due to increasing loads but also due to the proposed improved digestion process (full anaerobic digestion as opposed to the current partial digestion process). Projected biogas values are shown in Table 4.16. These values assume a specific gas production value of 15 cubic feet per pound of VS destroyed and a heating value of 550 Btu per cubic foot.

Table 4.16 Projected Biogas Values

Parameter	Minimum (ADA at Current Flow/Load Values)	Projected ADA	Projected ADMM
Without Primary Sludge Thickening			
Average Production (cfm)	59	105	129
Average Energy Content (MMBtu/hour)	1.9	3.5	4.3
With Primary Sludge Thickening			
Average Production (cfm)	57	102	125
Average Energy Content (MMBtu/hour)	1.9	3.4	4.1

Notes:
cfm cubic feet per minute

The BWRF could consider receiving grease and/or food waste to increase biogas production. Projected amounts of this high strength waste would be required to evaluate the impact of the additional load on proposed solids unit capacities and sizes. Organic grease wastes generally require debris removal, equalization, and often heating prior to being fed directly to anaerobic digestion. If the BWRF is considering accepting such waste to increase biogas production, additional processing would involve unloading solid food waste from trucks and conveying it into shredding and sorting machines to remove contaminants such as glass, metal, plastics, and rocks. A homogenous slurry would then be generated by processing the shredded solid waste through equipment such as a hydro-pulper where water is added. Once the slurry is screened for fine contaminants such as grit and sand, it would be pumped into storage tanks for equalization. It is recommended this solid waste slurry-preprocessing occur offsite due to footprint limitations within the BWRF and odor concerns.

4.12.2 Biogas Beneficial Use Alternatives Evaluation

The following two beneficial use alternatives were identified as the most likely to bring the BWRF a return on investment:

1. Upgrade the biogas into renewable natural gas (RNG) and inject it into an Xcel Energy (Xcel) pipeline. Note that Broomfield staff stated the Broomfield fleet crew is not interested in using RNG for fleet fueling.
2. Condition the biogas and use it in a cogeneration engine. Generated heat would be used for digester heating, and generated electricity would be used for general BWRF needs.

Analyses of these two alternatives are presented in the sections that follow. The analyses assume the new biogas system will be operational by 2028, as estimated in Chapter 7. Biogas production values for each year between 2028 and 2045 were estimated via a per capita production value calculated by dividing the projected biogas produced by the future digesters under current flow and load values (59 cfm, listed in Table 4.16) by the estimated 2022 service population. This per capita value was then multiplied by the projected population numbers for each year between 2028 and 2045.

4.12.2.1 Capital and Life Cycle Cost Assumptions

The economic analyses for the two biogas use alternatives include the following elements:

- Capital costs (including direct and indirect construction costs and engineering and administrative costs).
- O&M costs.
- Revenue generated (or costs offset).
- Payback period.

Cost estimates were prepared using pricing from similar projects, vendor quotes, and conceptual unit costs. Modifications to the scope as well as future fluctuations in the costs of material, labor, and equipment will affect final values.

A net present value (NPV) was developed for each alternative to enable a comprehensive total life cycle analysis comparison.

Capital Estimating Assumptions

Cost estimating was conducted by identifying equipment and construction costs in 2022 dollars and escalating those to 2027, the assumed midpoint of Phase 2 (as discussed in Chapter 7, the phase of the utility plan that includes construction of most proposed solids improvements, including the new beneficial biogas use system).

The total project cost estimates include direct and indirect costs as well as engineering, administrative, and legal services costs. At a Class 5 level of estimate, many of the contractor costs and other indirect costs are assumed to be allowances as a percentage of equipment procurement costs. Table 4.17 summarizes these assumptions. Further discussion of cost estimating can be found in Chapter 7.

Table 4.17 Construction Allowances, Contingencies, and Assumptions

Criteria	Assumption Used
Construction Allowances	
Equipment Installation	30% of equipment costs
Other Allowances (HVAC, architectural, structural, civil, EI&C)	10-30%
Contractor/Construction Contingency	25%
General Conditions, Contractor Mark-Ups, Escalation	
General Conditions Allowance	15%
General Conditions Overhead, Profit, Bonds, Mobilization	12.5%
Construction Cost Average Annual Escalation Rate	6%
Engineering and Administrative Costs	
Engineering, Legal, and Administrative Fees	18%

Notes:
EI&C electrical, instrumentation, and controls

Life Cycle Costs

Life cycle costs were calculated to determine the projected payback period for the two biogas use alternatives. Life cycle costs include O&M costs, operating cost savings, and revenue projections. Life cycle cost development assumed linear increases in the cost of energy, labor, and materials throughout the planning period.

All future costs were adjusted for inflation by applying an assumed annual escalation rate of 3 percent to the current costs for each year of the planning period. For comparison, all costs were calculated in terms of NPV for a planning analysis starting with construction in 2027 and operation in 2028 and ending in the planning year 2045. A 3.5 percent discount rate was assumed.

Life cycle unit cost assumptions are summarized in Table 4.18.

Table 4.18 Unit Cost Assumptions

Parameter	Value	Unit
Utility Cost Assumptions		
Electricity (Xcel) Rate(1)	$0.089	$/kWh
Natural Gas Rate(2)	$9.52	$/MMBtu, $/Dth
Renewable Identification Number (RIN) Cost/Revenue Assumptions		
Renewable Fuel Standard (RFS) Program Certification One-Time Cost in 2028	$150,000	$
RIN Brokerage Costs	20%	Percentage of RIN Revenue
Original Equipment Manufacturer (OEM) Management Costs	50%	Percentage of eRIN Revenue
Cellulosic Biofuel (D3) RIN Value(3)	$2.04	$/RIN
Electric RIN (eRIN) Value(4)	$0.31	$/kWh
RNG Cost/Revenue Assumptions		
Brown Gas Value(5)	$3.33	$/MMBtu, $/Dth
Biogas Upgrading System Annual Operating Cost	$0.0020	$/scf raw biogas
Biogas Upgrading System Annual Maintenance Cost	2%	of equipment costs
Cogeneration Cost/Revenue Assumptions		
Cogeneration Annual Operating Cost	$0.0024	$/scf raw biogas
Cogeneration Annual Maintenance Cost	2%	of equipment costs

Notes:
(1) Electricity rate calculated from the BWRF's 2022 Xcel electricity bill (including demand charges) divided by the BWRF's 2022 Xcel electricity usage for Meters A, C, D, E, and F.
(2) Natural gas rate calculated from the BWRF's 2022 natural gas cost divided by the BWRF's 2022 natural gas usage.
(3) Average D3 RIN value between 2015 and 2022 equals $2.04.
(4) eRIN value calculated from the average D3 RIN value and the eRIN equivalence value of 6.5 kWh/RIN proposed by EPA draft rulemaking published in December 2022 with a target effective date of January 1, 2024.
(5) Brown gas value taken as the wholesale natural gas price estimated to be 35 percent of the natural gas rate.

4.12.2.2 Financial Market Considerations

This section summarizes available financial incentive markets and provides some indication of their long-term viability and potential impact from current and future policies.

RNG and Renewable Electricity Financial Markets

The value of RNG can be broken into the physical natural gas value (e.g., brown gas) and the environmental attribute. The value of a physical molecule of gas is typically tied to a regional gas index. This evaluation assumed the brown gas value to be the wholesale natural gas value, taken as 35 percent of the natural gas rate Broomfield pays and therefore estimated as $3.33/MMBtu.

Most of the value of RNG comes from the environmental attribute. Opportunities to monetize this resource include the following:

- **RFS Program:** The RFS program is managed by the EPA and is used to offset carbon emissions in the transportation sector. Revenues are generated through the sale of RINs which represent 77,000 Btu of biogas.
- **Low Carbon Fuel Standard (LCFS) Programs:** LCFS programs are managed at either the state or regional level and establish compliance goals to reduce carbon emissions.
  - A few WRFs have received LCFS credits from the California program by packaging their facility-generated RIN credits with the credits from the dairy industry. However, this is becoming more difficult as additional dairy RNG projects come online and compete for LCFS credits. Carollo consequently did not include LCFS credit revenue in these analyses.
- **Voluntary Markets:** These local and regional programs are implemented by either corporations or regional natural gas utilities that are focused on sustainability. In some cases, the corporations/utilities may have compliance requirements to achieve long-term sustainability goals, some of which can be accomplished by using RNG.

The main value of renewable electricity has typically been associated with an offset of electricity purchase for a facility due to the produced electricity that can be used onsite. Other opportunities to monetize this resource include the following:

- **RFS Program:** As noted below, the RFS program recently defined a pathway to generate eRINs from electricity produced from qualifying renewable biomass and used to charge vehicles and offset fossil-based transportation fuel.
- **Renewable Energy Certificates (REC):** RECs are a market-based instrument issued when 1 megawatt-hour (MWh) of electricity is generated and delivered to the electricity grid from a renewable source.

RFS Program

The EPA's RFS Program creates the BWRF's largest opportunities for financial gain via beneficial biogas use. It was created under the Energy Policy Act of 2005 (https://www.epa.gov/renewable-fuel-standard-program) and established the first renewable fuel volume mandate in the U.S. The program requires oil and gas producers to purchase specified amounts of fuel credits each year to increase renewable fuel use in the transportation sector. Each 77,000 Btu of biogas (based on the lower heating value) used for vehicle fuel represents one RIN.

To become a RIN producer through the RFS program, Broomfield must become certified with the EPA. This certification is typically done by a third-party environmental attribute developer (i.e., RIN broker) but can also be done in-house. RIN brokers can also manage ongoing reporting and management as well as handle the sale of RINs to obligated parties (i.e., oil and gas producers). In exchange, they receive a management fee based on an agreed upon percentage of the RIN value, assumed for this project to be 20 percent. These analyses assume the employment of a RIN broker and include a $150,000 one-time certification and reporting charge (assigned to and expressed in 2028 dollars) for EPA registration as well as a 20 percent reduction in RIN revenue for management fees.

The RFS program defines the following four types of renewable fuels: cellulosic biofuel, biomass-based diesel, advanced biofuel, and renewable fuel. The biogas produced by municipal digesters can either be designated as cellulosic biofuel (D3) or advanced biofuel (D5).

The delineation between D3 and D5 biogas has a large impact on beneficial use economic analysis. Although the RNG and renewable electricity produced from D3 and D5 biogas are identical, the digester feedstock differs. A D3 RIN must be sourced from a primarily cellulosic feedstock (i.e., cellulose, hemicellulose, lignin) such as municipal wastewater, whereas D5 RINs are issued for fuels from any qualifying biomass outside of corn starch. Additional feedstock introduced at the facility (such as separately trucked-in grease and food waste) historically has led to the declassification of all biogas from D3 to D5 unless the separate feedstock is contained to a single digester (i.e., not mixed with municipal wastewater); then only that digester's biogas would be classified as D5. While feedstock like grease and food waste tends to produce greater amounts of biogas than municipal wastewater, and more biogas to utilize increases facilities' chances of financial payback, mass declassification of all biogas when feedstocks are mixed has a significant negative impact on economic analyses because a D5 RIN is worth significantly less than a D3 RIN.

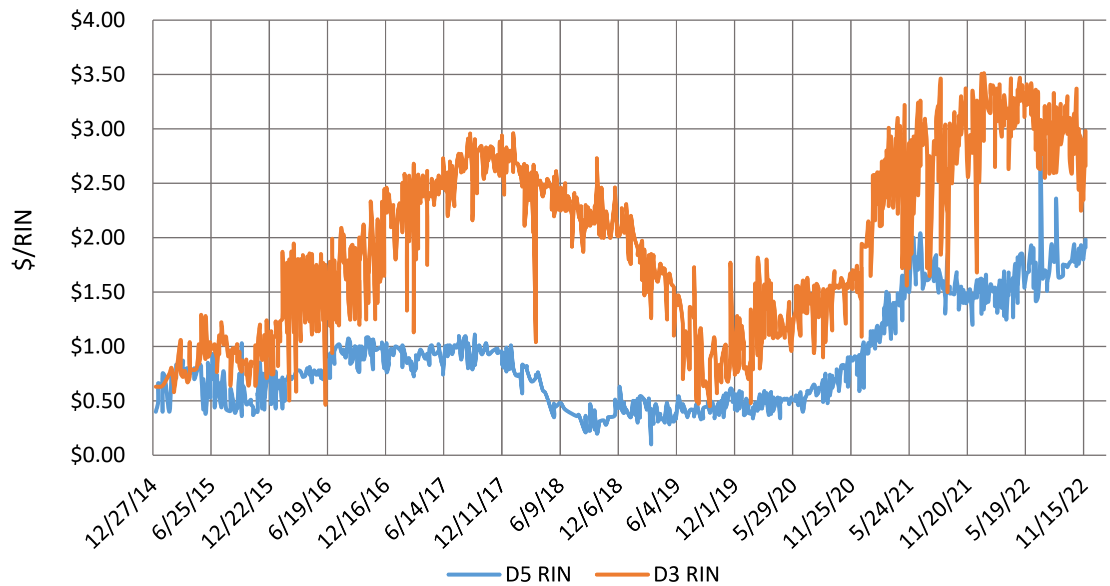
However, on July 12, 2023, the EPA published the Final RFS Rule for 2023, 2024, and 2025 (40 CFR Parts 80 and 1090) that finalizes the ability to apportion D3 and D5 RINs to biogas produced from municipal wastewater (D3) and external feedstocks (D5) co-mingled in the same anaerobic digester. If the BWRF were to accept grease and/or food waste in the future, the ability to partition biogas between D3 and D5 RINs significantly improves the potential for financial payback. The grease/food waste would increase production, and the BWRF could earn D5 revenue off that new additional biogas while maintaining D3 revenue from the original municipal wastewater production. These analyses assumed the BWRF will continue to only digest municipal wastewater and produce D3 RINs.

RINs are traded on the open market, and their value is dependent upon supply and demand, which is greatly influenced by the price of oil and renewable volume obligation (i.e., amount of RINs obligated parties have to purchase). When D3 RINs were first introduced to the market, they had a value of approximately $1.00/RIN. In 2022, D3 RIN values were around $3.50/RIN, their peak value. D5 RINs were also introduced at approximately $1.00/RIN, and their value remained stable for several years before dropping to a low of $0.10/RIN in early 2019. They are currently trading for about $1.58/RIN. Table 4.19 and Figure 4.3 illustrate average, minimum, and maximum D3 and D5 RIN pricing from 2015 through late 2022.

Table 4.19 D3 and D5 RIN Pricing[1]

Type of RIN	Average ($)	Minimum ($)	Maximum ($)
D3	$2.04	$0.46	$3.50
D5	$0.93	$0.10	$2.94

Notes:
(1) Source: RIN Trades and Price Information | EPA (EPA, 2023).



Source: RIN Trades and Price Information (EPA, 2023)

Figure 4.3 Historical RIN Pricing

RFS Program – eRINs

The RFS regulations have and continue to include a pathway for electricity produced from biogas to generate eRINs, which could significantly impact the financial payback potential of the cogeneration alternative. While the EPA has not yet approved any such project, in draft rulemaking from December 2022, they proposed "regulatory changes to prescribe how RINs from renewable electricity (eRINS) would be implemented and managed under the RFS program" with the goal "to address many of the outstanding issues which to date have prevented EPA from registering parties to allow them to generate eRINs produced from qualifying renewable biomass and used as transportation fuel." The draft rulemaking proposed an eRIN equivalence value of 6.5 kWh/RIN; combining this value with the average D3 RIN price presented above ($2.04/RIN) yields a D3 eRIN price of $0.31/kWh. However, OEMs (i.e., electrical vehicle manufacturers like Tesla, Ford, etc.) would manage the eRIN process and be entitled to 50 percent of the eRIN value, meaning the BWRF would only receive 50 percent of generated eRIN revenue. Importantly, as long as the cogeneration process includes a connection to the grid (whether utilized or not), current understanding indicates the BWRF would be able to both use generated electricity onsite (offsetting electricity costs) and earn eRIN revenue. While the EPA originally intended to finalize the eRIN program by June 14, 2023, in the Final RFS Rule for 2023, 2024, and 2025 published July 12, 2023, the EPA delayed finalization due to the volume and complexity of stakeholder comments received in response to the December 2022 draft. Strong stakeholder interest will continue to push the EPA; however, to progress the eRIN program, these analyses assumed BWRF will be able to capitalize on eRINs by 2028.

Voluntary Markets

Similar to the vehicle fuel markets, voluntary purchasers are utilizing RNG as a part of their companies' solutions to meet environmental, social, and governance goals. Potential voluntary purchasers include the following (BlueSource, 2021).

Voluntary purchasers also include natural gas utilities starting to diversify their sustainability portfolios into the RNG markets. Some large utilities like Xcel and the Southern California Gas Company (SoCalGas) are providing long-term offtake agreements for sizable volumes of RNG. SoCalGas is committing to providing their customers with 20 percent RNG by 2030. If SoCalGas is to achieve this commitment, they will need over four times the amount of RNG currently provided to the transportation markets for RINs. This will significantly increase the demand-side economics and should increase value for RNG producers.

With D3 and D5 RIN prices at historic highs in 2022, the availability of RNG to voluntary buyers has been minimal, causing buyers to increase their price point dramatically. Table 4.20 shows the pricing variability for voluntary markets and illustrates the significant increases in markets based on current conditions and drivers towards RNG sustainability goals.

Table 4.20 Historical Voluntary Market Pricing

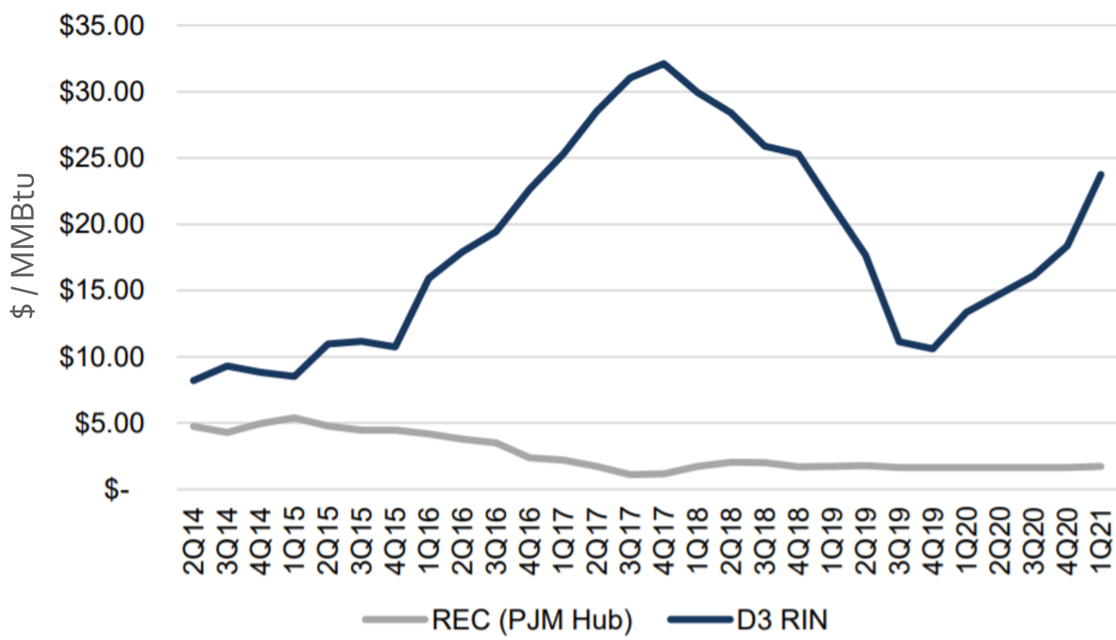
	Low (5 years ago)	Average (Past 2 to 5 years)	Current
Voluntary Market Pricing	$8-10/MMBtu	$10-12/MMBtu	$18-23/MMBtu

It is reasonable to assume 100 percent of the BWRF's RNG could be purchased by a single voluntary buyer. Similar to the RFS program, a third-party carbon broker typically manages the sale of RNG onto the voluntary market for WRFs.

Renewable Energy Certificates

To comply with renewable mandates, electric utilities can purchase RECs, a market-based instrument issued when 1 MWh of electricity is generated and delivered to the electricity grid from a renewable source. Utilities may also generate their own RECs by generating and delivering renewable electricity themselves. RECs are also available in voluntary markets as utilities want to publicly disclose their use of renewables; however, the voluntary market is separate from and incremental to the mandatory market to avoid double claims on the same megawatt-hour. RECs are the accepted legal instrument through which renewable energy generation and usage claims are substantiated in U.S. markets, and are supported by various state governments, utility commissions, trade organizations, and U.S. case law. It should be noted that the Renewable Portfolio Standards (RPS) programs and prices vary from state to state; however, in general, RECs that supply mandatory markets tend to hover just below the cost of non-compliance with a given RPS state program.

RECs under RPS programs have historically traded at a significant discount to D3 RIN prices under the RFS (Figure 4.4). The premium received for RINs explains why most of the RNG is consumed by the transportation sector. Due to the EPA's recent proposed rulemaking and anticipation that the BWRF can generate and sell eRINs from renewable electricity generation, RECs were not included in the cogeneration evaluation.



Source: EPA, Bloomberg

Figure 4.4 RECs under RPS Programs Compared with D3 RIN Prices

Inflation Reduction Act

The passage in 2022 of the federal Inflation Reduction Act (IRA) provides a pathway to reduce the capital costs of biogas projects. As part of this act, the Section 48 Energy Investment Tax Credit program has been expanded to include biogas capture and interconnection distribution. Under this program, through a single upfront investment tax credit (ITC), biogas system owners are eligible for up to a 40 percent base investment tax credit with an additional 10 percent if the project complies with federal mandates such as prevailing wage provisions, apprenticeship mandates, and domestic production of materials. Implementing guidance is still forthcoming, so the actual ITC percentage could vary. These regulations and guidelines are anticipated to be issued by the federal government in the summer of 2023 and should be reviewed in developing a project financing plan. To be eligible, facilities must begin construction before January 1, 2025. Tax exempt facilities are expected to be eligible for cash payment in lieu of tax credits. Since information on this IRA funding is limited, a sensitivity analysis was performed on the RNG and cogeneration alternatives described below assuming a 30 percent capital cost savings.

4.12.2.3 RNG Pipeline Injection

This alternative involves capital investment to upgrade the biogas for pipeline injection with potential financial payback via the sale of brown gas and RINs. More specifically, a biogas upgrading system would need to be purchased to remove H_2S, siloxanes, volatile organic compounds (VOC), CO_2, and moisture from the biogas and compress it prior to sending it to an Xcel Interconnect Facility for injection into a natural gas supply pipeline.

These financial analyses assumed use of a membrane biogas upgrading system. Four biogas upgrading technologies are generally used in the industry to produce pipeline-quality RNG: membrane, pressure swing adsorption, amine, and water wash. Membrane and pressure swing adsorption are "dry" upgrading systems that physically separate CH_4 from CO_2 and other impurities based on molecule size, pressure, and ionic charge. Amine and water wash are "wet" upgrading systems that separate CH_4 from CO_2 and other impurities by dissolving the impurities into a liquid stream. A membrane system was assumed as they are widely used at WRFs, are cost-effective at lower size ranges, and have simpler O&M compared to the other upgrading technologies.

The total project cost estimate for pipeline injection of RNG is estimated to be $10.1 million as shown in Table 4.21. This estimate is based on an equipment quote for a three-pass membrane biogas upgrading system provided by Unison Solutions, Inc. In three-pass systems, the third stage of membranes is used to treat the tail gas (remove methane from the tail gas) in lieu of either thermal oxidation or direct discharge into the atmosphere. The quoted cost includes an H_2S removal system, a gas compression and moisture removal system, a siloxane removal system, and a CO_2 removal system.

Costs for a concrete pad and drilled piers, an equipment enclosure, and an Xcel Interconnect Facility were also included in addition to allowances and contingencies.

Table 4.21 Estimated RNG Pipeline Injection Project Cost

Description		Cost
Direct Costs (includes construction allowances)		
Sitework		$150,000
Concrete Pad		$90,000(1)
Drilled Piers		$153,000(2)
Three-Pass Membrane Biogas Upgrading System		$1,090,000(3)
Equipment Enclosure		$181,000(3)
Equipment Installation	30%	$381,300
Piping/Valve Allowance	30%	$381,300
Subtotal Equipment and Itemized Direct Costs		**$2,426,600**
EI&C Allowance	25%	$607,000
Construction Contingency – Estimating, Design Development	25%	$758,400
Construction Escalation to 2027		$1,283,000(4)
General Conditions Allowance	15%	$761,000(5)
General Conditions Overhead, Profit, Bonds, Mobilization	12.5%	$634,000
Total Construction Cost		**$6,470,000**
Engineering, Permitting, Construction Management	18%	$1,165,000
Xcel Energy Interconnect Facility		$2,500,000
Total Project Cost Estimate (2027 $)		**$10,135,000**

Notes:
(1) Assumes a 50-foot by 50-foot pad with a 1.5-foot thickness.
(2) Assumes 24-inch drilled piers that extend 35 feet below ground surface and are distanced (center-to-center) approximately 12 feet apart.
(3) Cost from quote for example project scaled to BWRF's 2045 projected flow rate.
(4) Assumes an average annual escalation rate of 6 percent.
(5) Includes the cost of equipment needed across multiple project phases (e.g., cranes).

Life cycle costs associated with the RNG pipeline injection alternative include the cost to purchase natural gas to heat the digesters, membrane system O&M costs, labor costs, and RIN certification and reporting fees. Potential annual revenues include the sale of brown gas to the pipeline and either RIN sale or sale to the voluntary markets. These costs and revenues were considered through 2045, the planning year for this utility plan, and were used to calculate a total NPV for this alternative. Table 4.22 presents the NPV for the adopted baseline condition that assumes RIN sale (as opposed to sale to the voluntary markets) at the assumed D3 RIN price of $2.04 per RIN as documented in Table 4.19.

Table 4.22 Estimated RNG Pipeline Injection NPV – Baseline Condition

Description	Cost
Estimated Project Cost (2027 $)	**$10,135,000**
Annual Costs	
Natural Gas Cost for Digester Heat, $/year	$74,000
Membrane Operating Cost, $/year	$91,000
Equipment Maintenance/Labor Cost, $/year	$28,000
Annual Revenues	
Natural Gas (Brown Gas) Sale to Pipeline, $/year	$82,000
D3 RIN Revenue, $/year(1)	$521,000
Net Annual (Costs)/Revenues, $/year	**$402,000**
Payback Period, years	**25**

Notes:
(1) Brokerage fees (assumed to be 20 percent of RIN revenue) subtracted from earned revenue amount. A $150,000 cost was included in 2028 ($145,000 2027 NPV cost) for registration of BWRF's biogas with the EPA.

To evaluate the financial viability of a potential RNG injection system based on changing future conditions as well as potential IRA savings, sensitivity analyses were developed and compared to the baseline condition presented above. The first analysis considered the RIN pricing variability presented in Table 4.19; Table 4.23 summarizes the average, lowest, and highest D3 RIN values realized for the 2015-2022 period and the resulting NPV and payback.

Table 4.23 Estimated RNG Pipeline Injection NPV – Variable D3 RIN Pricing

	2015-2022 Average (Baseline)	Minimum Value	Maximum Value
D3 RIN Price ($/RIN)	$2.04	$0.46	$3.50
NPV ($ million)	($2.9)	($10.2)	$3.8
Payback (years)	25	N/A	13

The second analysis considered sale to the voluntary markets rather than RIN sale. Based on the current voluntary market pricing of $21/MMBtu, the payback period increases to 30 years.

The third analysis considered a 30 percent capital cost reduction via the IRA (and D3 RIN sale at average pricing). Inclusion of IRA funding reduces the payback period to 20 years. The baseline assumptions yield a payback period of 25 years. Sale to the voluntary market under current pricing conditions increases that period to 30 years while assumption of IRA reduction decreases it to 20 years. The payback period could potentially be further shortened by the addition of high-strength waste as discussed above, pending an evaluation of any capital improvements needed to accept that waste.

4.12.2.4 Cogeneration

This alternative involves capital investment for biogas conditioning and cogeneration and heat recovery systems but with financial payback via the sale of eRINs and electricity purchase savings. Specifically, a biogas conditioning system would need to be purchased to remove H_2S, siloxanes, and moisture from the biogas and compress it prior to sending it to a new cogeneration engine that would generate heat and electricity to be recovered for beneficial use at the BWRF. The heat would be captured via heat exchangers to heat the new digesters (thereby reducing the amount of natural gas the BWRF needs to buy), and the electricity would generate eRINs as well as be used onsite to offsite electricity costs.

The total project cost estimate for cogeneration is estimated to be $13.9 million as shown in Table 4.24. This estimate uses a quote for a biogas conditioning system provided by Unison Solutions, Inc., for a similar project. The quoted cost includes an H_2S removal system, a gas compression and moisture removal system, and a conditioning equipment enclosure. The cost for a siloxane removal system was included by assuming it would be the same as the quoted H_2S removal system cost. The cost of the cogeneration and heat recovery equipment was estimated via Carollo experience on similar projects, and the cost for a cogeneration/heat recovery equipment enclosure was assumed to be the same as the equipment enclosure cost used in the RNG pipeline injection evaluation. Costs for a concrete pad and drilled piers were also considered in addition to allowances and contingencies.

Table 4.24 Estimated Cogeneration Project Cost

Description		Cost
Direct Costs (includes construction allowances)		
Sitework		$150,000
Concrete Pad		$90,000(1)
Drilled Piers		$153,000(2)
Hydrogen Sulfide Removal System		$256,000(3)
Siloxane Removal System		$256,000(4)
Gas Compression/Moisture Removal System		$809,000(3)
Cogeneration and Heat Recovery Equipment		$872,000(5)
Enclosure for Compression/Moisture Removal System		$148,000(3)
Enclosure for Cogeneration/Heat Recovery Equipment		$181,000(3)
Equipment Installation	30%	$756,600
Piping/Valve Allowance	30%	$756,600
Subtotal Equipment and Itemized Direct Costs		**$4,428,200**
EI&C Allowance	25%	$1,107,000
Construction Contingency – Estimating, Design Development	25%	$1,383,800
Construction Escalation to 2027		$2,340,000(6)
General Conditions Allowance	15%	$1,389,000(7)
General Conditions Overhead, Profit, Bonds, Mobilization	12.5%	$1,157,000

Description		Cost
Total Construction Cost		**$11,805,000**
Engineering, Permitting, Construction Management	18%	$2,125,000
Total Project Cost Estimate (2027 $)		**$13,930,000**

Notes:
(1) Assumes a 50-foot by 50-foot pad with a 1.5-foot thickness.
(2) Assumes 24-inch drilled piers that extend 35 feet below ground surface and are distanced (center-to-center) approximately 12 feet apart.
(3) Cost from quote for example project scaled to BWRF's 2045 projected flow rate.
(4) Assumed to be the same cost as the hydrogen sulfide removal system.
(5) Cost from Carollo project experience.
(6) Assumes an average annual escalation rate of 6 percent.
(7) Includes the cost of equipment needed across multiple project phases (e.g., cranes).

Life cycle costs associated with the cogeneration alternative include the cost to purchase natural gas to heat the digesters (reduced from the RNG pipeline injection alternative due to the heat recovered from the cogeneration engine), cogeneration O&M costs, labor costs, and eRIN certification and reporting fees. Potential annual revenues include eRIN sale and savings via using the generated electricity on site and thereby not needing to purchase as much electricity from the grid. These costs and revenues were considered through 2045, the planning year for this utility plan, and were used to calculate a total NPV for this alternative. Table 4.25 presents the NPV for the adopted baseline condition that assumes eRIN sale at the assumed price of $0.31/kWh described above, derived from the average D3 RIN price of $2.04/RIN via an eRIN equivalence value of 6.5 kWh/RIN.

Table 4.25 Estimated Cogeneration NPV – Baseline Condition

Description	Cost
Estimated Project Cost (2027 $)	**$13,930,000**
Annual Costs	
Natural Gas Cost for Digester Heat, $/year	$4,000
Cogeneration Operating Cost, $/year	$109,000
Equipment Maintenance/Labor Cost, $/year	$49,000
Annual Revenues	
Electricity Savings, $/year	$233,000
eRIN Revenue, $/year(1)	$412,000
Net Annual (Costs)/Revenues, $/year	**$475,000**
Payback Period, years	**29**

Notes:
(1) OEM entitlement to 50 percent of eRIN value subtracted from earned revenue amount. A $150,000 cost was included in 2028 ($145,000 2027 NPV cost) for registration of BWRF's biogas with the EPA.

To evaluate the financial viability of a potential cogeneration system based on changing future conditions as well as potential IRA savings, sensitivity analyses were developed and compared to the baseline condition presented above. The first analysis considered the RIN pricing variability discussed for the RNG pipeline injection alternative; Table 4.28 summarizes the average, lowest, and highest eRIN prices based on D3 RIN prices and the resulting NPV and payback.

Table 4.26 Estimated Cogeneration NPV – Variable eRIN Pricing

	2015-2022 Average (Baseline)	Minimum Value	Maximum Value
D3 RIN Price ($/RIN)	$2.04	$0.46	$3.50
eRIN Price ($/kWh)(1)	$0.31	$0.071	$0.54
NPV ($ million)	($5.4)	($11.1)	($0.065)
Payback (years)	29	N/A	18

Notes:
(1) Calculated via the eRIN equivalence value of 6.5 kWh/RIN provided by the EPA.

The second analysis considered a 30 percent capital cost reduction via the IRA (and eRIN sale at average pricing). Inclusion of IRA funding reduces the payback period to 22 years.

The baseline assumptions yield a payback period of 29 years. This payback period is about the same as that estimated for the baseline RNG pipeline injection alternative (25 years) despite the cogeneration alternative's higher estimated project cost. This result is due to the cogeneration alternative's reduced natural gas need, opportunity for electricity savings, and high eRIN revenue potential (due to the high efficiency of electric vehicles and thus an increased ability to offset transportation fuel). As with the RNG pipeline injection alternative, the cogeneration payback period could potentially be shortened by the addition of high-strength waste. If the BWRF elects to move forward with the cogeneration alternative, further investigation is warranted to confirm the viability of eRINs. The information provided in this report is based on the EPA's draft rulemaking from December 2022 which was not finalized in the Final RFS Rule for 2023, 2024, and 2025 published in July 2023. Carollo recommends closely following developments in the eRIN program to determine when it is appropriate to initiate design.

4.12.2.5 Greenhouse Gas Emissions Analysis

To allow for the comparison of annual GHG emissions for RNG pipeline injection and cogeneration relative to the 2021 baseline emissions inventory, Carollo used the GHG Inventory Tool and populated it with details for RNG pipeline injection and cogeneration. This allowed for a side-by-side comparison of the two alternatives, as well as comparison to the baseline inventory. The GHG estimates are based on the same methodologies, emissions factors, and global warming potentials as the baseline emissions inventory described in Chapter 1.

Data Sources

Data used to estimate the GHG emissions associated with the biogas utilization alternatives included:

- 2021 plant data for parameters that are assumed to remain unchanged through 2028, e.g., distances from chemical suppliers.
- Scaling 2021 plant data linearly with projected population increase.
- Projected 2028 values from design data and engineer's estimates.

Beneficial Biogas Utilization Alternatives GHG Estimates and Summary

For the two alternatives, annual direct and indirect GHG emissions (after offsets) were estimated to be approximately 9,640 mt CO_2e for use as RNG and 9,178 mt CO_2e for use in cogeneration (not including biogenic CO_2 emissions). As noted in Chapter 1, CO_2 emissions associated with biogenic fuel sources, such as biogas, are included in EPA reporting requirements but are not the focus of emission reductions to incentivize their use.

Each alternative has specific ways in which it offsets a portion of BWRF's emissions, and both alternatives include the existing solar panels at BWRF, which further reduce the plant's purchased electricity demand. All offsets are accounted for as Scope 3 sources. Refer to Table 4.30 and Figure 4.5 for a breakdown of GHG emissions by alternative, category, and source. Percentages are taken as percent of total emissions after offsets, not including biogenic CO_2.

RNG provides emissions offsets by creating an alternative fuel source for transportation use. This is quantified by a reduction in emissions that would be associated with an equivalent amount of diesel fuel combustion that would have been required to fuel those vehicles, resulting in an offset of 1,041 mt CO_2e/year.

RNG-specific emissions are associated with tail gas venting and combustion of the RNG as an alternative transportation fuel. During the process of upgrading biogas to be injected into the natural gas pipeline, CO_2, sulfur, VOCs, and other gases are removed. An estimated 703 mt CO_2e/year will be emitted from tail gas venting and 1,348 mt CO_2e/year will be emitted from combustion of the RNG in compressed natural gas vehicles. Of this, 660 mt CO_2e/year from tail gas venting and 1,286 mt CO_2e/year from combustion is biogenic CO_2.

Cogeneration provides emission offsets by generating a portion of BWRF's electricity and heat onsite from biogas, reducing the demands of the plant for fossil fuel-based natural gas and purchased electricity. This, in turn, reduces the emissions that would be associated with fossil fuel-based electricity generation and natural gas generation and combustion. Cogeneration would provide an offset of 1,730 mt CO_2e/year and is reflected in Figure 4.5 as reductions in purchased electricity and natural gas.

Cogeneration-specific emissions are produced from the combustion of biogas. Of the estimated 1,011 mt CO_2e/year emitted by the cogeneration alternative, 1,006 mt CO_2e/year are biogenic CO_2.

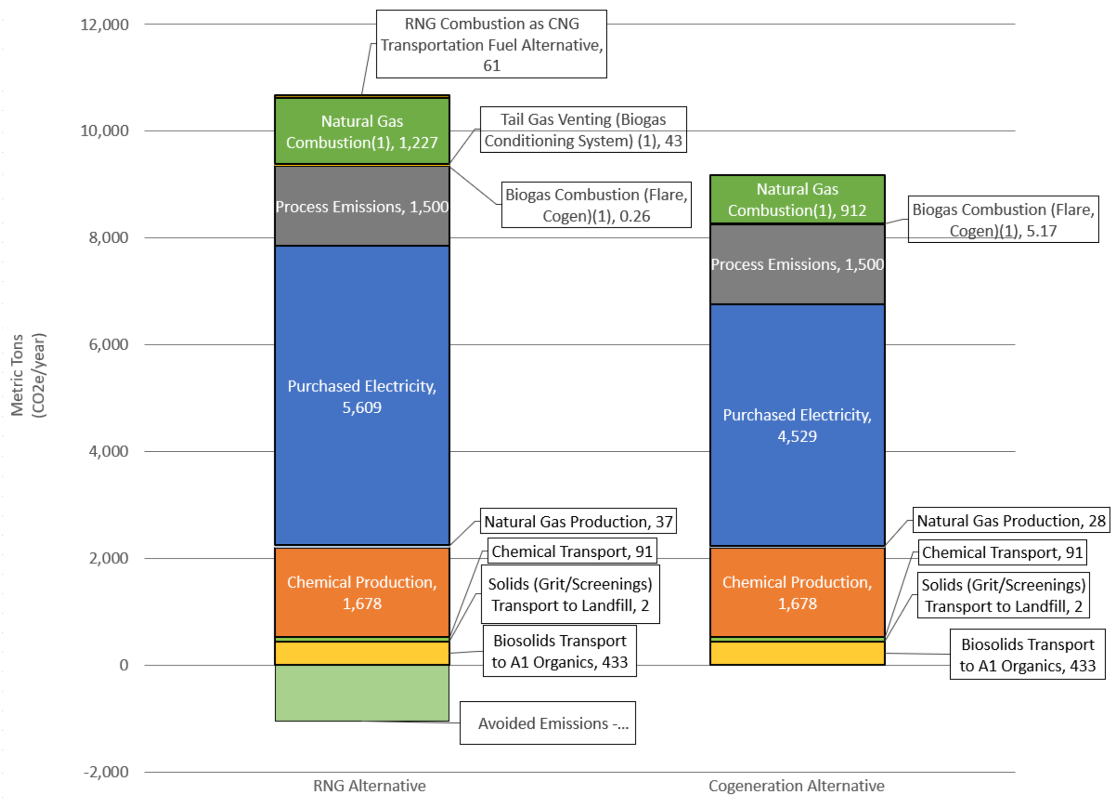
Table 4.27 BWRF Biogas Utilization Alternatives GHG Emissions and Offsets Estimates Comparison

Source	2028 RNG Alternative Emission (mt CO_2e/year, %)	2028 Cogeneration Alternative Emission (mt CO_2e/year, %)
EMISSIONS		
Scope 1[(1)]	**3,481**	**3,423**
Scope 1 (Excluding Biogenic CO_2)[(1)]	**2,770 (28.7%)**	**2,417 (26.3%)**
Natural Gas Combustion	1,227 (12.7%)	912 (9.9%)
Biogas Combustion, Biogenic CO_2	50	1,006
Biogas Combustion, CH_4 and N_2O	0.26 (0.0%)	5.17 (0.1%)
Process Emission	1,500 (15.6%)	1,500 (16.3%)
Tail Gas Venting, Biogenic CO_2	660	N/A
Tail Gas Venting, CH_4	43 (0.4%)	N/A
Scope 2 – Purchased Electricity	**5,609 (58.2%)**	**4,529 (49.3%)**
Scope 3	**3,589[(7)]**	**2,232[(7)]**
Scope 3 (Excluding Biogenic CO_2)	**2,303 (23.9%)**	**2,232 (24.3%)**
Natural Gas Production	37 (0.4%)	28 (0.3%)
Chemical Production	1,678 (17.4%)	1,678 (18.3%)
Chemical Transport	91 (0.9%)	91 (1.0%)
Grit Screenings to Landfill	2 (0.0%)	2 (0.0%)
Biosolids Transport	433 (4.5%)	433 (4.7%)
Offsets[(2)]	-1,115	-1,730
Avoided Purchased Electricity	-73	-1,153
Avoided Purchased Natural Gas	N/A	-576
Avoided Diesel Combustion (Vehicles)	-1,041	N/A
TOTAL EMISSIONS SUMMARY[(1)(2)]		
Scopes 1, 2, and 3 (Emissions)	12,679	10,183
Scopes 1, 2, and 3 (Biogenic CO_2 Emissions)	-1,997	-1,006
Offsets	-1,115	-1,730
Scopes 1, 2, and 3 (Emissions and Offsets without Biogenic CO_2)	9,640	9,178

Notes:

(1) Biogenic CO_2 emissions from the combustion of biogas are included in total emissions estimates since they are required for reporting purposes (e.g., EPA's Mandatory GHG Emissions Reporting Rule), but they are not included in percentage of total emissions calculations since they are not the focus of emissions reductions.

(2) Offsets from solar power generation and cogeneration are captured in the reduction of purchased electricity, natural gas combustion, and natural gas production.



Notes:

(1) Emission source that is included in federal reporting requirements. Applicability of regulations must be evaluated.

(2) Offsets from PV and cogeneration (heat and electricity generation) is accounted for as a reduction in purchased electricity, natural gas combustion, and natural gas production.

Figure 4.5 Biogas Alternatives GHG Emissions and Offsets by Source

4.13 Summary

The existing solids handling process suffers from lack of redundancy, aging infrastructure, and inadequate capacity. It requires major improvements not only to be able to handle projected flows and loads from future population growth but also to meet the BWRF's process and sustainability goals.

The BWRF currently lacks a dedicated primary sludge thickening process but achieves successful WAS thickening with the existing DAFT unit. This existing thickening process notably lacks redundancy, and Carollo suggests implementing not only a new DAFT unit capable of handling projected flows and loads, but a second, redundant unit that can also function as a primary sludge gravity thickener for operational flexibility and optimization.

The existing anaerobic digestion infrastructure is at end-of-life and lacks the capacity to achieve full digestion. Carollo recommends building four new digesters sized such that two can handle projected flows and loads while achieving digestion that produces Class B biosolids. The third digester would be a redundant unit, and the fourth would serve as a secondary digester that provides pre-dewatering storage in addition to digester redundancy, ultimately offering the BWRF sufficient digester capacity capable of handling loads beyond current projections.

The existing centrifuge dewatering process works well, and Carollo recommends maintaining dewatering centrifuges and installing upsized units capable of handling projected flows and loads. The current solids loadout system lacks post-dewatering storage, and Carollo suggests consideration of modifying the Solids Handling Building to install silos/hoppers such that the BWRF is not subject to the financial and logistical challenges that accompany needing to store the solids in hauling trucks. Carollo also recommends constructing a new centrate equalization tank, sized to handle the projected flows and loads. This new tank gains importance with the future improved digestion process, which would increase the nutrient load in the centrate that must be equalized prior to returning to the liquid treatment process to maintain liquid process capacity.

The existing BWRF flares all generated biogas. Capture and beneficial use of that biogas would align with Broomfield's GHG emission reduction goals with the added benefit of potential financial incentive. Either upgrading the biogas to RNG and injecting it into an Xcel pipeline or implementing cogeneration are the two alternatives most likely to support those goals and provide Broomfield with financial incentives (credit) and a revenue stream. The former option offers brown gas sale and RIN revenue, while the latter offers electricity savings and potential eRIN revenue. While the RNG pipeline injection alternative has a lower estimated project cost, the cogeneration alternative, assuming Broomfield will be able to earn eRIN revenue, represents a higher net annual revenue, and the two alternatives are ultimately characterized by similar estimated payback periods (25 and 29 years, respectively). Additionally, the estimated GHG emissions associated with each biogas utilization alternative are similar, with emissions from RNG estimated as only 5 percent higher than cogeneration.

As noted in Chapter 3, the BWRF's projected influent flows should be better characterized before design is executed.

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Chapter 5

SATELLITE FACILITY EVALUATION

5.1 Introduction

With the potential limitations on future expansion of the BWRF, the anticipated future growth of the population of Broomfield warrants consideration of a satellite water reclamation facility to handle some of the anticipated new flow. The intent of this evaluation is to develop a concept of such a facility, including siting, collection system considerations, wastewater unit processes, effluent disposal, opinion of cost, timeline for project development, estimation of potential implications for flows and loads at the BWRF, and consideration of impacts on other utility operations of Broomfield as a consequence of building such a satellite facility.

This chapter discusses the evaluation approach used in developing this satellite facility concept, the anticipated flow and load conditions such a facility would face, a discussion of proposed wastewater processes, and a discussion of potential alternatives to the construction of this facility.

This evaluation is not intended to serve as a conceptual or preliminary engineering report, but instead as the initial review of the concept of a satellite WRF to help guide Broomfield's discussions on next steps, as the detailed development of a completely new wastewater facility is a considerable undertaking in terms of time and expense. If a satellite WRF warrants further consideration, future assessments will include more detailed evaluation of location and process alternatives.

5.2 Timeline for Project Development

The new satellite facility should be operational by the early 2030s if it is constructed to ease demand and costs of growth at the BWRF. Implementation of this facility would not preclude the need to carry out many of the BWRF improvements proposed in previous chapters; a fourth secondary treatment train and new solids treatment units would still need to be constructed to meet BWRF's current rated capacity and address infrastructure at end-of-life. However, timing of the satellite should be targeted to mitigate need for the BWRF hydraulic capacity improvements scheduled for commissioning in 2033 (Phase 4, see Chapter 7 – Recommendations for BWRF Improvements for detail on the timing of proposed improvements). The satellite facility would need to be operational by the early 2030s to avoid needing to implement both the BWRF hydraulic improvements and the satellite facility.

Carollo estimates the satellite facility would require a minimum of five years to implement considering permitting, land acquisition, design, and construction needs. To have the satellite facility functional in 2033, that effort would need to begin in 2027 at the latest – ideally sooner given uncertainty around the required permitting and land acquisition efforts. It should also be noted construction of the satellite facility would impact many of the BWRF improvements included in the Utility Plan's capital improvement plan (CIP). For example, if some of the projected flows and loads are diverted from BWRF, it might be beneficial to size the new processes so they can more easily turndown for lower flows. The extent of improvement needed for the south secondary treatment train (scheduled for Phase 3) might also be impacted.

Overall, it would be beneficial if a decision on the future of the satellite facility was made prior to the start of design of BWRF improvements so overall wastewater treatment requirements are managed as effectively and efficiently as possible.

5.3 Description of Evaluation Process

The evaluation has been completed through discussions with Broomfield regarding the concept for a satellite facility and the issues surrounding such a concept, a review of data provided by Broomfield including information incorporated into previous chapters of this report and new information made available for this analysis, and the use of current design standards for new wastewater facilities.

5.3.1 Information Used from Prior Chapters

The primary information used from previous chapters consisted of the per-capita flow and load projections found in Table 1.1 of Chapter 1 – Basis of Planning. In order to maintain consistency with other planning, Carollo reused these factors when developing the flow and load projections for a potential satellite facility.

5.3.2 Additional Geospatial and Modeling Information

Broomfield provided tabular projections of population growth by planning zone in the city and the geospatial boundaries of those planning zones, as well as the geospatial layout of Broomfield's wastewater collection system. This information was used to assess ideal locations for a satellite facility on the basis of existing infrastructure and proximity to future population growth.

5.3.3 Treatment Processes

Carollo made preliminary treatment process selections and layouts based on knowledge of the direction of future Colorado wastewater treatment facilities and design information from similar greenfield projects.

5.4 Future Conditions

As discussed in Chapter 1, Broomfield's population is expected to undergo considerable growth over the coming decades, with the additional wastewater flow and loads and the corresponding needed upgrades to BWRF representing the primary driver for the evaluation of a satellite wastewater treatment facility.

5.4.1 Spatial Distribution of Population Growth

Broomfield's population growth is not expected to be evenly distributed throughout the service area; rather, the majority of growth is expected to occur in the northeast corner along Interstate 25 (I-25), including the development of an area east of I-25 where no sizeable resident population or wastewater service currently exists. Figure 5.1 shows the spatial distribution of projected population growth from 2023 to 2050, in relation to Broomfield's 16 planning areas.

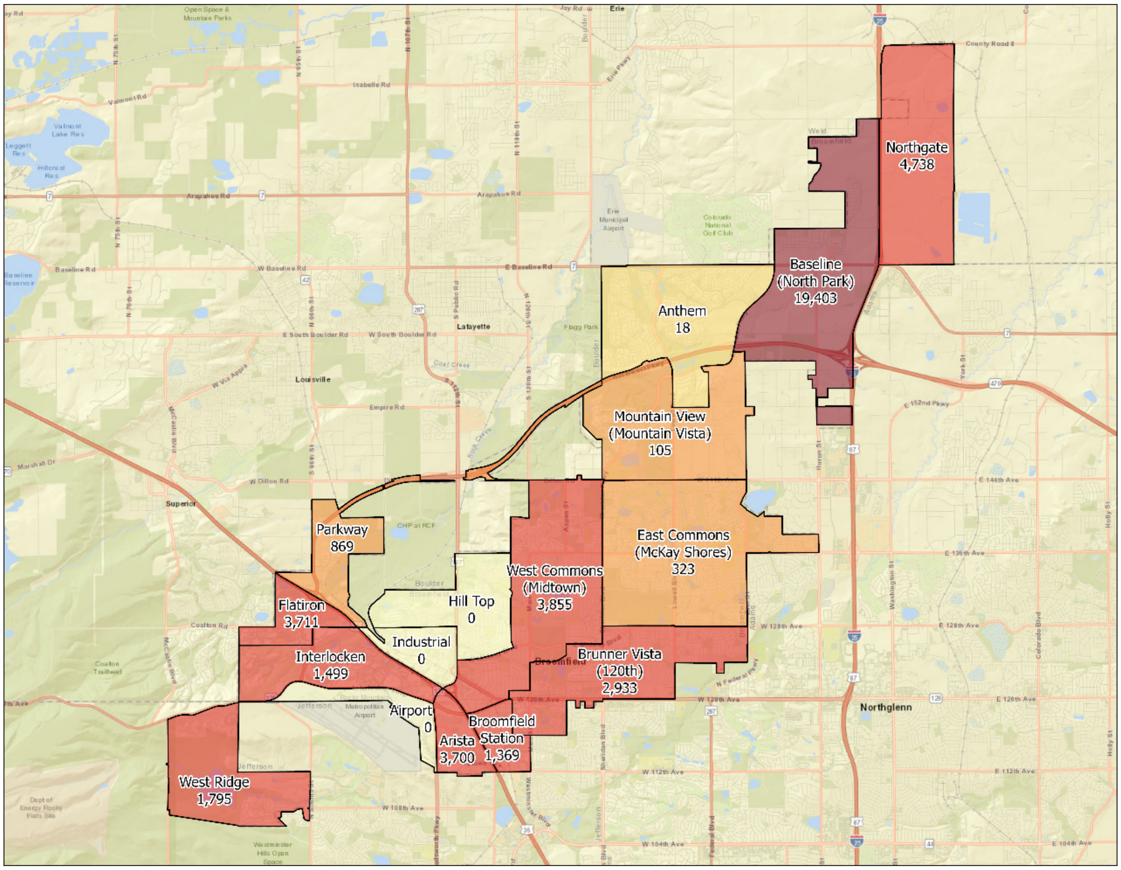

Figure 5.1 Projected Broomfield Population Growth by Planning Area, 2023-2050

5.5 Proposed Facility Design Criteria

This section discusses the main concepts considered in this evaluation, which would be expected to drive decision-making on the specifics of a potential satellite wastewater treatment facility should satellite treatment efforts be advanced further.

5.5.1 Proposed Facility Location and Service Area

In discussions with Broomfield staff, the ideal location for a satellite wastewater treatment plant should have the following attributes:

- Location near where projected growth is expected to occur.
- A currently undeveloped area.
- Access to a main road.
- Access to a water body for discharge of treated wastewater (ideally the same one as BWRF for water rights and permitting reasons).
- With sufficient space for the proposed facility.

The area east of I-25, known in Broomfield's planning as "Northgate," is almost completely undeveloped, and this planning area plus the neighboring "Baseline" planning area are expected to account for approximately 60 percent of Broomfield's population growth from 2023 to 2050. Carollo did not perform a detailed land analysis for this evaluation. An existing parcel east of I-25 was selected for conceptual planning purposes, and the parcel only represents a feasible option.

It is approximately 29 acres, is located approximately 1.5 miles from Big Dry Creek into which BWRF currently discharges, and is adjacent to Baseline Road. The parcel can be seen in Figure 5.2, along with Big Dry Creek.

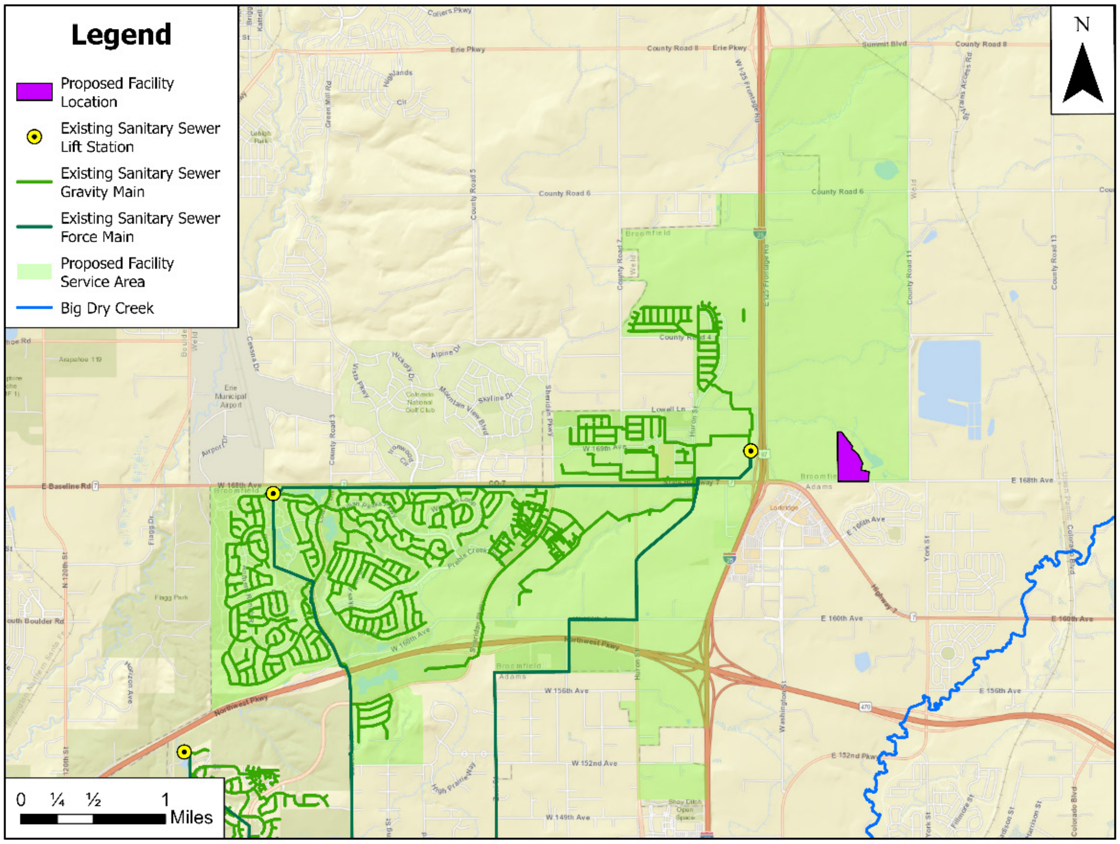

Figure 5.2 Conceptual Facility Service Area and Location

Compiled data from existing Colorado facilities comparing capacity and site area is shown in Figure 5.3. As a starting feasible location, the identified parcel appears sufficient for the satellite facility which will have an expected capacity of 4 mgd (see Section 5.5.2 – Projected Influent Flows and Loads).

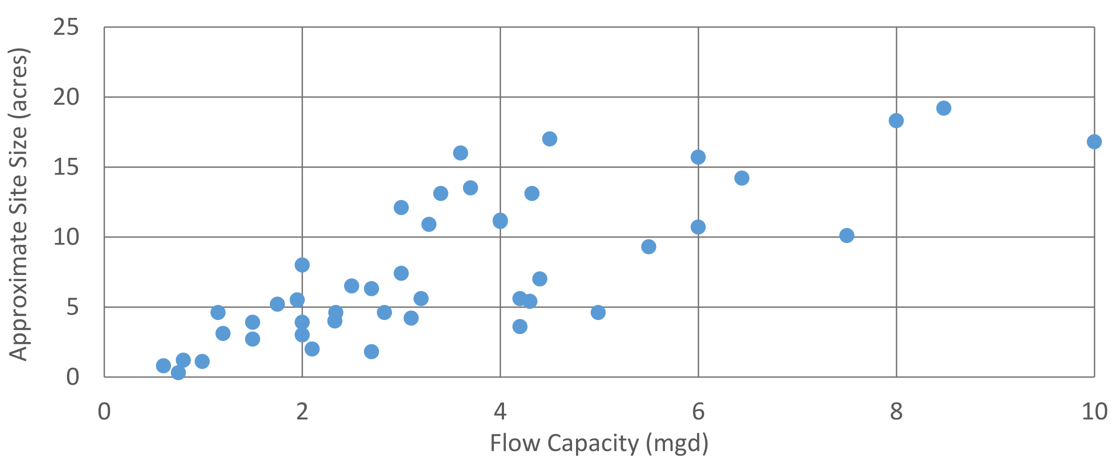

Figure 5.3 Comparison of Colorado Wastewater Treatment Facilities' Flow Capacities to Site Areas

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In terms of service area, the facility would ideally service enough homes to reduce the need for some planned expansion at BWRF. Based on Carollo's work planning improvements for BWRF, it was estimated that a projected future flow reduction of roughly 4 mgd ADMMF would be required to have an impact on needed improvements at that facility. The Northgate and Baseline areas with their projected populations would produce approximately 2.9 mgd ADMMF of wastewater flow at buildout. Accordingly, it would be necessary to have the satellite facility serve additional areas.

Inclusion of the built-out "Anthem" planning area immediately west of Baseline would increase buildout flows to a projected 3.8 mgd ADMMF. The Anthem area currently has a wastewater force main connection to the Baseline area for sending flow to BWRF that may be able to be reused to send flows to a satellite facility instead.

Accordingly, the proposed service area for a satellite facility would consist of the Northgate, Baseline, and Anthem planning areas as shown in Figure 5.2, along with existing Broomfield wastewater collection infrastructure in the area. Table 5.1 provides the projected planning area populations through 2050 and the combined service area population.

Table 5.1 Projected Facility Service Population 2023-2050

Area	Present (2023)	2030	2040	2050
Anthem	8,486	8,486	8,486	8,486
Baseline	4,083	14,545	22,429	22,429
Northgate	27	27	1,333	4,768
Total (Satellite WRF Service Area)	**12,516**	**23,058**	**32,248**	**35,683**

5.5.2 Projected Influent Flows and Loads

The proposed influent flow was sized to be sufficient to reduce the need for hydraulic improvements at BWRF, currently planned for Phase 4 of efforts, with a proposed schedule of design and construction from 2029 through 2033. Eliminating this improvement was estimated to require the satellite facility to be able to process approximately 4 mgd ADMMF of wastewater flow at buildout.

The per capita factors used for evaluation of a satellite facility are the same as those used to develop flow and load projections for BWRF as discussed in Chapter 1.

5.5.2.1 Average Daily Annual Flow and Load

Average daily annual flow and load were based on per capita values of 87 gpcd and 0.19 pounds per capita per day (ppcd) biochemical oxygen demand (BOD), respectively. With the projected service population of 35,683, these values translate to an ADA flow and load of 3.1 mgd and 6,780 ppd BOD at buildout.

5.5.2.2 Projected Average Daily Maximum Month Flow and Load

Average daily max month flows were based on a per capita value of 107 gpcd. With a projected service population of 35,683 at buildout, this would represent a buildout flow of approximately 3.8 mgd, which if set as 95 percent of the design value would yield a design ADMMF of approximately 4.0 mgd and a BOD load of approximately 9,000 ppd.

Table 5.2 shows projected flows from 2030 to 2050.

Table 5.2 Projected Flows, 2030-2050

Flow Scenario	2030	2040	2050
ADAF	2.0	2.8	3.1
ADMMF	2.6	3.6	4.0

5.5.3 Effluent Disposal and Limits

Effluent disposal at a satellite facility could be handled several ways, including direct discharge to a receiving water body, return to BWRF for discharge there, or sending discharge to a potable reuse facility.

For the purposes of this evaluation, it was assumed the satellite facility would be able to discharge directly to Big Dry Creek as BWRF currently does – this would likely make permitting such a facility considerably easier and would reduce some issues related to water rights and required return flows that might arise from discharging to another water body. In discussion with Broomfield staff, it was initially noted that the specific location of discharged effluent along Big Dry Creek was not a major concern from a water rights perspective, as long as effluent was discharged to that water body at some point.

With the same receiving water body, the effluent limits for a satellite facility discharging to Big Dry Creek would likely be the same as those currently in place for BWRF, as discussed in Chapter 1, except where CDPHE may have more stringent standards for a new discharge. A satellite wastewater treatment facility would also need to meet future discharge limits such as temperature and reduced nutrients. The selection of treatment processes and conceptual layout discussed later in this chapter incorporate these current and future discharge requirements into the evaluation.

5.6 Proposed Facility Treatment Processes and Layout

5.6.1 Facility Alternatives

The following two alternatives are considered for the satellite facility:

- A complete treatment facility that treats both the liquid and solids streams.
- A scalping facility that only treats the liquid stream. Solids would be returned to the collection system and sent to BWRF for treatment.

The benefit of a complete facility is localized treatment of both liquids and solids. Treating both streams would reduce demands on the portion of the collection system that feeds BWRF and the solids units at BWRF. However, as discussed in Chapter 4 – Solids Handling Evaluation, much of BWRF's existing solids infrastructure is nearing end of life, is currently without the capacity to provide full treatment, and/or lacks redundancy. Even if a portion of projected future solids is treated at the satellite facility, new, larger solids units will still need to be constructed at BWRF. Furthermore, consolidating all solids at BWRF for treatment would maximize the volume of biogas BWRF can produce via anaerobic digestion and beneficially recover for environmental and financial gain (see Chapter 4 for discussion of beneficial biogas use options).

Both facility alternatives are considered in the discussion below.

5.6.2 Proposed Treatment Processes

Both the proposed complete and scalping facility options include the following major unit processes:

- Headworks.
- MBR activated sludge aeration.
- MBR submerged membrane filtration.
- UV disinfection.
- Odor control.

The complete facility option additionally includes the following major solids unit processes:

- Aerobic digestion.
- Dewatering.

These preliminary selections, specifically the proposed MBR and aerobic digestion processes, are discussed below.

5.6.2.1 Proposed Secondary Treatment Process - MBR

For this preliminary conceptualization, Carollo assumes the satellite facility (whether complete or scalping) would employ an MBR secondary treatment process. MBR treatment includes an activated sludge bioreactor for preliminary-treated wastewater coupled with submerged membrane filtration for solids separation and removal of organic matter and pathogens larger than the membrane pore size (see Chapter 3 – Liquids Stream Evaluation for a more detailed process description). While primary clarification is often provided upstream in larger installations to mitigate membrane fouling, it is not required in smaller installations such as this satellite facility. As described in Chapter 3, MBR is an "intensified" process that works to maximize treatment capacity per unit surface area. That is, it allows for a significantly higher MLSS concentration when compared to the conventional BNR process and therefore requires a smaller footprint. The membranes also reduce footprint by eliminating the need for secondary clarifiers.

While a reduced footprint is generally beneficial, the key driver for the MBR process selection is regulatory. To meet the low anticipated Regulation 31 nutrient limits, many new Colorado facilities are being planned around membrane technologies given they produce a higher quality effluent. It should be noted that while Regulation 31 limits are still being developed, it is uncertain how they will be applied in wastewater discharge permits and whether MBR treatment alone would be sufficient to comply.

It should be noted that EQ basins are not required at MBR facilities although the MBR process is sensitive to peak hour flows and is typically designed around them. Equalization is therefore not included in the list of major unit processes. However, equalized flow still benefits and eases process operation, and Broomfield could explore the implementation of a basin if the option for a satellite facility warrants further analysis and/or design. The volume of that basin would need to be coordinated with the wet well volume of the facility's influent lift station (likely Northlands Lift Station).

5.6.2.2 Proposed Solids Process – Aerobic Digestion

Carollo assumes a 4 mgd complete satellite facility with an MBR secondary treatment process would use aerobic rather than anaerobic digestion. This assumption is rooted in overall plant size as well as the absence of primary clarification upstream of the MBR process. The liquid treatment process would send only WAS to the solids processes rather than a mixture of primary sludge and WAS as is the case at BWRF, and aerobic conditions are typically preferred to anaerobic conditions for the digestion of only WAS.

While aerobic digesters require the additional operational cost of aeration and do not produce biogas that can be beneficially recovered as in anaerobic digestion, they tend to represent lower capital costs for smaller facilities like the satellite facility. Additionally, given its size, the satellite facility would likely not be able to produce enough biogas to generate a payback on its own anaerobic digesters. The potential for benefit from biogas recovery would be maximized by instead implementing a scalping satellite facility and sending all solids to the anaerobic digesters at BWRF. In the scalping facility option, the solids would be separated by and sent to the collection system after MBR filtration – that is, they would be sent after being thickened. Conveyance of thickened solids risks issues in the collection system. These issues could be explored and mitigated via communication with existing Colorado scalping facilities.

It should be noted a separate thickening process would not necessarily be required upstream of digestion due to the high MLSS concentrations characteristic of the MBR process and therefore the relatively high concentration of the resultant solids.

5.6.3 Proposed Layout and Process Summary

The proposed unit processes were roughly sized using dimensions created for a similar potential greenfield MBR facility in Colorado. Figures 5.4 and 5.5 show conceptual layouts for these processes in the identified land parcel. These layouts are meant to display feasibility and should not be taken as recommendations for implementation.

Influent wastewater could be pumped to headworks from Northlands Lift Station, located immediately west near I-25. The liquids stream would move from headworks through the MBR aeration basins and membrane system and then into UV disinfection. The disinfected flow would then move to an effluent pump station to be discharged to Big Dry Creek (the need for an effluent pump station is ultimately dependent on the hydraulics created by the equipment and surrounding land elevations). Both facility conceptual layouts include the space for potential PFAS treatment and effluent temperature cooling technologies that may be needed prior to environmental discharge to meet future regulatory limits. The option to pump the effluent flow to a potable reuse facility could also be explored.

The complete satellite facility layout shown in Figure 5.4, unlike the scalping facility layout in Figure 5.5, also includes solids treatment processes. WAS from the MBR membrane system would be conveyed to the aerobic digesters. Digested sludge would then be dewatered in the solids handling building with technology such as centrifugation (as at BWRF) prior to disposal/land application. The scalping facility layout, unlike the complete facility layout, includes a solids pump station to send WAS from the MBR membrane system back to the collection system.

While both the complete and scalping conceptual layouts fit comfortably in the space provided by the identified parcel, the absence of solids units in the scalping layout creates more free space and flexibility for additional infrastructure such as potential equalization and storage tanks.

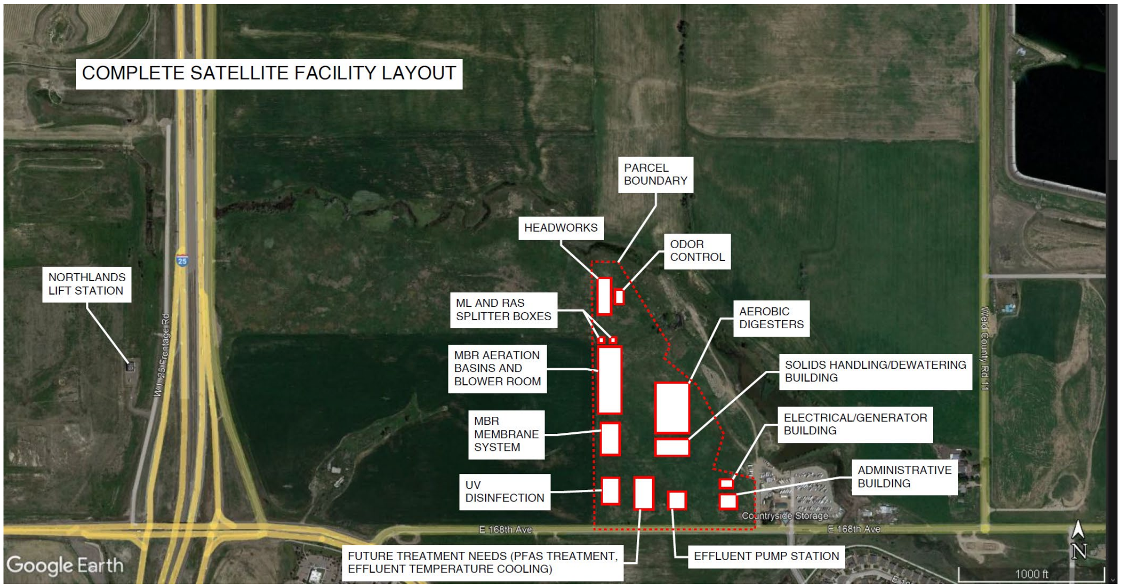

Figure 5.4 Conceptual Layout for Complete Satellite Facility – Treats Liquid and Solids Streams

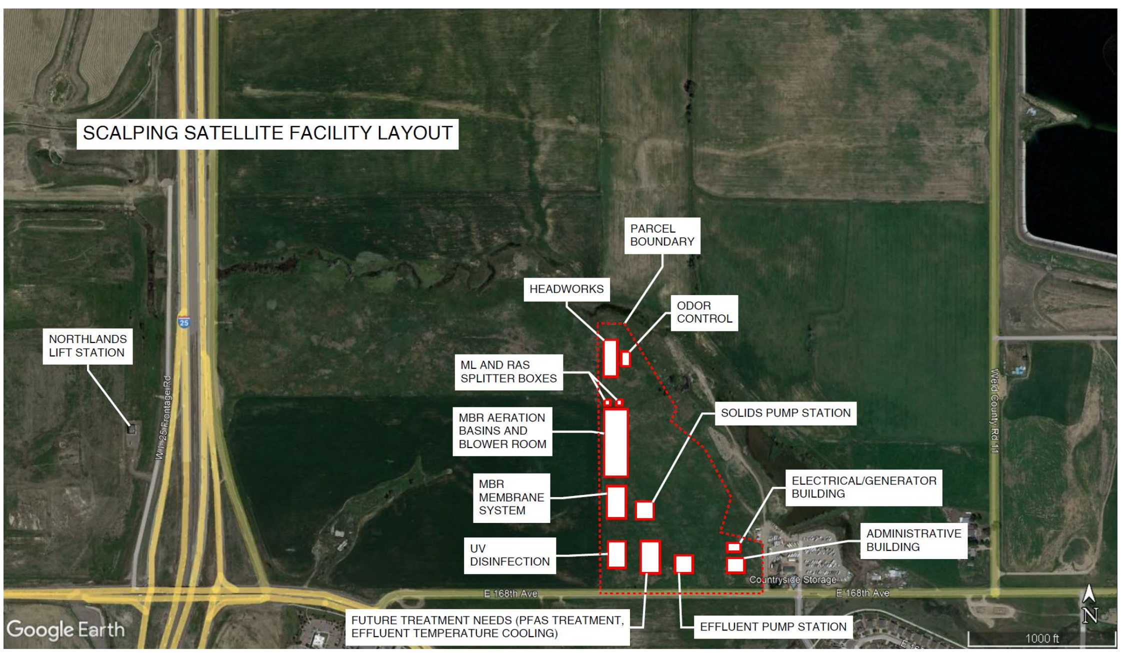

Figure 5.5 Conceptual Layout for Scalping Satellite Facility – Only Treats Liquid Stream

5.6.3.1 Solar Power Considerations

Discussion with Broomfield staff revealed a preference to power the satellite facility with solar panels to help meet Broomfield's sustainability goals. Based on estimates from a similar MBR project, Carollo approximates the satellite facility's peak power demand at 4,000 kilowatts (kW). In Colorado, solar panels require about 75 sf of space per kW of solar panel capacity. Broomfield would therefore require roughly 300,000 sf, or 7 acres, of footprint to power the facility with solar panels pending battery storage. The scalping facility layout presented above may have enough open green space to accommodate this acreage, but constructing a solar panel field in that space would significantly limit available footprint for potential equalization/storage tankage. Furthermore, the surrounding treatment process structures may shade panels installed at ground level. Broomfield could consider installing solar panels on top of buildings/structures or else purchasing a neighboring parcel to accommodate the solar panels.

5.7 Satellite Facility Cost

Considering this satellite facility is still in the earliest phases of conception and significant uncertainty surrounds what the land acquisition and permitting process would look like, a reasonable quantitative cost estimate is not defined at this time. However, Carollo has provided a qualitative estimate of how providing no satellite facility (and only upgrading BWRF per this Utility Plan's CIP), providing a scalping satellite facility, and providing a complete satellite facility financially compare in Table 5.3.

Table 5.3 Qualitative Cost Comparison of Satellite Facility Options

No Satellite Facility (Only BWRF Upgrades)	Scalping Satellite Facility and BWRF Updates	Complete Satellite Facility and BWRF Upgrades
$$	$$$$	$$$$$

Implementing a satellite facility represents a significantly more expensive endeavor than not and only carrying out improvements at BWRF. An entirely new facility creates not only more capital expense via the new equipment, buildings, and collection system infrastructure but also more operational and labor expense. Two facilities would require more energy investment than one, and effective operations would likely require an entire second set of staff dedicated to the satellite facility (preliminary consideration suggests around 10 personnel would be needed). The satellite facility options also require the major additional costs of purchase of a land parcel for facility siting and new facility permitting expenses. Importantly, the satellite facility does not significantly eliminate the need for improvements at BWRF; most of the improvements proposed in the CIP would still need to occur. The satellite facility's additional costs would not be balanced by significant associated savings via reduced BWRF upgrades.

5.8 Conclusion and Recommendations for Further Analysis

A potential satellite wastewater treatment facility in the northeastern corner of Broomfield's service area could potentially take pressure off of BWRF by capturing the majority of Broomfield's projected population growth over the 2023 to 2050 planning horizon. Table 5.4 summarizes the pros and cons associated with implementing a satellite facility versus just enacting improvements at BWRF.

Table 5.4 Satellite Facility Alternative Criteria Analysis and Comparison

Criterion	No Satellite Facility (Only BWRF Upgrades)	Satellite Facility and BWRF Upgrades
Cost	Less expensive	More expensive
Footprint	Limited onsite space	Would be built in undeveloped area with potential for plenty of space; could reduce space demand at BWRF
Sequencing	Complex with existing infrastructure and process needs	Simple regarding the satellite facility as it would be a greenfield project; sequencing needs for BWRF upgrades would still exist
Treatment	Consolidated treatment; maximizes biogas production for beneficial recovery	Localized treatment; potential to design and operate facility according to the specific quality of wastewater from future northeast development

Such a facility would be a complex undertaking, and this evaluation is only the smallest first step in the development of such a concept. Many components of the development of such a project were not addressed here, and would require more detailed analysis to further elucidate, including those described below.

5.8.1 Collection System Evaluation

The wastewater collection system is a key element that was not extensively addressed in this evaluation. To collect wastewater for a satellite facility, Broomfield would need to restructure the existing collection system in the facility's service area, assumed in this evaluation to include the Anthem, Baseline, and Northgate planning areas. Existing sewer force mains would need to be rerouted, and a new one added underneath I-25 to send wastewater to the proposed facility location east of I-25.

As growth is expected east of I-25 without such a force main currently in place, this is an effort that Broomfield will likely need to undertake within the planning horizon. Detailed hydraulic modeling of the existing collection system will likely be needed in conjunction with that effort in order to evaluate the hydraulic capacity of the existing system to pump the new growth to BWRF, and that same modeling could be used as a basis for evaluating needed changes to pump to a satellite facility.

5.8.2 Potential Consolidation with Neighboring Utilities

An additional option for Broomfield could eliminate the need for a satellite facility altogether. Consolidation or partnering with a neighboring utility to transfer wastewater flow from a portion of Broomfield's wastewater collection area to the partnering entity's wastewater facility is an option to offload flow from BWRF.

For example, Northglenn has a wastewater treatment plant immediately east of the proposed site of Broomfield's satellite facility, and Westminster and Metro Water Recovery operate wastewater treatment facilities within some proximity. Broomfield staff have a strong desire to maintain control of Broomfield's wastewater effluent due to concerns over water rights and logistical challenges related to interagency agreements, and as such a detailed analysis of the potential of such an option was not explored in this evaluation.

5.8.3 Plant Siting Analysis

For the purposes of this evaluation, a parcel in the Northgate area was selected to host the proposed facility footprint. One of the next steps in the development of a potential satellite facility would be a detailed evaluation of suitable sites to further land acquisition efforts. The parcel selected here may well be an ideal candidate in that regard, as it is currently owned by a developer that likely intends to construct residences on some of the other parcels they own in the Northgate planning area. Detailed siting evaluation would need to include an analysis of hazards such as floodplains, access to discharge locations, ease of acquisition, and other factors.

5.8.4 Influent Characterization

It was assumed during this evaluation that the flow and load per capita values used for BWRF in earlier chapters would be sufficient for evaluating a proposed satellite facility. However, flow and load characteristics can change in accordance with the types of customers served by the collection system – the predominantly residential areas included in the proposed service area may have different flow patterns and loads than more mixed-use areas further south in Broomfield, a discrepancy which may only grow as residential development concentrates in the northeast area that a satellite facility is proposed to serve.

A thorough monitoring and sampling program at multiple points in any proposed service area would be vital to developing more detailed design flows and loads for a satellite facility.

5.8.5 Detailed Design and Cost Re-Evaluation

The level of design detail contained in this evaluation was intended to provide the broadest picture of a potential satellite facility, and as such the cost information included in this evaluation is limited. The next stage of design – a detailed conceptual design effort – would include process alternatives analysis, equipment selection, and other components that would enable a more thorough evaluation of potential costs.

Chapter 6

POTABLE REUSE FEASIBILITY STUDY

6.1 Introduction

The rapidly increasing population described in prior sections of this Utility Plan impacts all aspects of Broomfield's provision of utility services to its customers. An aspect not previously addressed in this document is the availability of potable water to supply the demands of the increasing service area population, which could potentially be partially met through purifying recycled water to augment drinking water supplies.

Broomfield acquires drinking water from the following sources: Denver Water provides treated drinking water on a wholesale basis, and the Colorado-Big Thompson and Windy Gap systems of the Northern Colorado Water Conservancy District (NCWCD) provide raw water to Broomfield's drinking water treatment facility (WTF). These sources have finite supply limits, and moreover the water that comes from the NCWCD sources is at least partially reusable after it is treated at the BWRF, based on the water rights associated with each source.

Broomfield currently supplies some of its customers' irrigation demands using reusable BWRF effluent via a non-potable reuse system. However, this system is not anticipated to be expanded into certain new growth areas and is not expected to fully utilize the available reusable effluent due to the seasonality of irrigation demands and limitations on recycled water storage capacity. Potable water reuse – purifying the recycled water to standards suitable for augmenting Broomfield's drinking water supplies – offers an opportunity to fully utilize the available reusable effluent from the BWRF.

Potable reuse augments potable water supplies, either through IPR or DPR. In an IPR system, treated wastewater is treated at an advanced water purification facility (AWPF) prior to discharging it to an environmental buffer (e.g., a stream or surface water reservoir or recharge to a groundwater aquifer) that supplies a water treatment facility for potable water treatment and distribution. DPR uses an AWPF to purify water without discharging it to an environmental buffer. A DPR AWPF can be used to augment raw water supply at a traditional water treatment facility ("raw water augmentation," as practiced at the only operational DPR facility in the U.S. at Big Spring, Texas), or can purify the recycled water to drinking water standards and send it directly to the potable water transmission and distribution system ("finished water augmentation," similar to the system now under design for El Paso Water Utilities in Texas).

This chapter discusses the feasibility of implementing DPR or IPR in Broomfield, including a summary of relevant regulations, a discussion of treatment alternatives, an analysis and cost estimate for treatment and conveyance for conceptual DPR and IPR projects, and a discussion of a roadmap to implementation of such a project.

6.2 Regulatory Summary

This section describes the regulations in Colorado related to DPR and IPR. CDPHE has specific regulations for DPR, as summarized below. Colorado does not have regulations specifically designed to govern IPR; the relevant regulations for that form of potable reuse are described in the subsequent section.

6.2.1 Direct Potable Reuse Regulatory Considerations

DPR in Colorado is regulated under Regulation 11, Colorado Primary Drinking Water Regulations, Section 11.14, the "Direct Potable Reuse Rule." The DPR Rule became effective in January 2023 after several years of development by CDPHE and stakeholder workgroups and formal adoption by the Colorado WQCC in November 2022, defining the requirements to implement advanced water purification for either raw water augmentation or finished water augmentation. This section summarizes the rule; it is recommended that individuals planning out a DPR project review the full rule in Regulation 11.

The DPR Rule contains the following requirements that reflect the unique nature and concerns associated with implementing DPR:

- **Prior Approval Requirements** that specify the minimum elements of an application to CDPHE for DPR, including a detailed plan with the elements described below.
- **Communications and Public Outreach Program,** specifying the development of a written plan for informing customers about the proposed DPR program.
- **Enhanced Source Water Control Program,** requiring a written plan to reduce, eliminate, or alter the nature of constituents of concern in the treated wastewater source by identifying and controlling contributions in the wastewater collection system.
- **DPR Operations Program,** comprising a written plan detailing how DPR will be put into practice at an operational level, including ensuring appropriate operator certification, communication links between wastewater and water operational staff, a combined water/wastewater operational manual, monitoring plans for the wastewater treatment facility, detailed plans related to how exceedances will be identified and addressed, and a communications plan that describes how the public will be informed about reuse operations, water quality, and incidents.
- **Wastewater effluent monitoring** prior to submitting an application, as described in Section 6.2.1.1 of this chapter.
- **Treatment Technique Requirements for Pathogen Reduction** included in the plan for AWPF treatment, including a minimum of three separate pathogen barriers as described in Section 6.2.1.2 of this chapter.
- **Treatment Technique Requirements for Chemical Reduction** included in the plan for AWPF treatment, including advanced oxidation and one or more additional chemical removal processes, as described in Section 6.2.1.3 of this chapter.

6.2.1.1 Effluent Monitoring Requirements

CDPHE identifies several water quality parameters in Section 11.14(6)(b) to be monitored in the proposed wastewater effluent at a critical control point. Monitoring must be conducted at regular intervals for at least 12 consecutive months prior to submitting an application. The parameters and their required monitoring frequency are included in Table 6.1.

Table 6.1 Pre-Application Monitoring Requirements for DPR Projects in Colorado

Sampling Required Every 15 Minutes		Sampling Required Every Month	
Ammonia	Conductivity	Nitrate and Nitrite	Lead and Copper(1)
pH	Temperature	Inorganics in 11.19(2)(1)(2)	Organics in 11.21(2)(1)(2)
Turbidity	UV absorption at 254 nm (for TOC)	Radionuclides in 11.22(2)(1)(2)	Disinfection byproducts in 11.25(1)(1)(2)
Effluent flow rate			

Notes:
(1) Monitoring only required during pre-application sampling period, not required during operational phase.
(2) 5 CCR 1002-11, section as noted (i.e., 11.19(2), 11.21, etc.).
nm nanometer
TOC total organic carbon

Section 11.14(6)(b)(ii) also requires monthly TOC sampling for 12 months inside the potable water distribution system to determine the recalcitrant TOC (rTOC). The rTOC is the system-specific background TOC concentration, which is used in determining TOC removal requirements for the AWPF.

Extensive monitoring is also required during the operation of a DPR system, though some of the monthly elements required for sampling during the application phase are not required during the operational phase.

6.2.1.2 Treatment Technology Requirements for Pathogens

In Section 11.14(7) of the DPR rule, CDPHE lays out the specific pathogen reduction and disinfection residual requirements for DPR programs.

Treatment technologies used in a DPR system must have a minimum of three technologies for pathogen reduction. These technologies must include at least:

- One disinfection step consisting of UV or ozone treatment.
- One filtration step consisting of reverse osmosis (RO), conventional or direct filtration (including ozone/biofiltration), or a CDPHE-approved alternate filtration step.
- A third disinfection or filtration step.

The disinfection system must achieve a specific log reduction of pathogens across the technologies, of at least:

- 10-log treatment of *Cryptosporidium.*
- 10-log treatment of *Giardia lamblia.*
- 12-log treatment of viruses.

CDPHE may approve lower log-removal requirements for these pathogens on the basis of detailed wastewater characterization. However, under no circumstances will log removal requirements be less than:

- 5.5-log treatment of *Cryptosporidium.*
- 6-log treatment of *Giardia lamblia.*
- 8-log treatment of viruses.

CDPHE describes how log removal values are credited to individual treatment processes in Section 11.17(7) of the DPR Rule. There are also specific monitoring requirements for various types of disinfection and filtration treatment technologies described in Section 11.14(7)(c), including residual disinfectant concentration.

6.2.1.3 Treatment technology requirements for chemicals

In Section 11.14(8), CDPHE lays out the specific chemical reduction technology requirements for a DPR system. Any DPR system must include chemical barriers that include an advanced oxidation process, plus either RO or a combination of adsorption (e.g., GAC) and an additional technology approved by CDPHE.

The DPR Rule requires extensive monitoring for TOC, drinking water MCLs, and site-specific indicator compounds approved by CDPHE. In particular, monitoring requirements include thresholds for investigating causes of elevated TOC in the purified water. If TOC concentrations exceed the 75th percentile of rTOC (the "alert limit"), actions must be taken to investigate the cause. Above the TOC action limit (1.5 times the 95th percentile of rTOC), actions must be taken within 72 hours to investigate the cause and resolve the situation.

6.2.2 Indirect Potable Reuse Regulatory Considerations

CDPHE does not have, nor has it indicated an intent to develop, separate regulations for IPR. CDPHE maintains that IPR systems are effectively governed via other existing regulatory frameworks. For example, CDPHE permits wastewater discharges to a receiving water body based on the designated beneficial use of that receiving water (the "environmental buffer" in this IPR scenario). If the beneficial use includes drinking water supply, water quality parameters and limits in the discharge permit will reflect that use. At the drinking water facility, the Safe Drinking Water Act governs the capture and treatment of "raw" water diverted from its source, which would include water discharged from the water reclamation facility to the environmental buffer.

Broomfield has experience with both sets of regulations with the currently separate operations of its potable water and wastewater systems. It is anticipated that the regulatory and compliance regime associated with developing an IPR system will not be considerably different than existing permit requirements. However, it would be prudent to consider implementing some form of an AWPF if Broomfield were to move forward with an engineered IPR system, in consideration of site-specific factors associated with the water body to be used as the environmental buffer and the relative locations of the discharge and diversion along that water body.

6.2.3 BWRF Current Performance Relative to Regulations

As part of developing the Wastewater Utility Plan, effluent water quality data from BWRF and additional water quality information related to drinking water system TOC concentrations were analyzed.

Ultimately, purified water sourced from the BWRF would need to meet Safe Drinking Water Act standards regardless of whether DPR or IPR is chosen.

Under either approach, advanced treatment could be sited at any point between or at the BRWF or Broomfield's WTF. Considering site layouts and availability of space for additional infrastructure, BWRF is not a viable site for AWPF processes, but an AWPF could be sited at the water treatment plant on property adjacent to existing processes.

BWRF's effluent data was obtained from Discharge Monitoring Report submittals pursuant to its NPDES permit for the current fiscal year. The monitored parameters covered by the primary drinking water standards and contained within this data are presented in Table 6.2, along with the relevant MCL. As shown, BWRF effluent currently meets the majority of MCLs for which effluent data is available; the exceptions are chromium, where BWRF's average sample is just below the MCL and maximum sample exceeds it, and radium 226 + radium 228, where the average sample is well below the MCL, but the maximum sample is at (but not exceeding) the MCL.

Table 6.2 BWRF Effluent and National Primary Drinking Water Regulations MCLs

Parameter	MCL	BWRF Maximum	BWRF Average
Arsenic, total [as As]	0.01 mg/L	0.00079 mg/L	0.00039 mg/L
Arsenic, total recoverable	0.01 mg/L	0.00052 mg/L	0.00033 mg/L
Beryllium, total recoverable [as Be]	0.004 mg/L	0.00035 mg/L	0.0002 mg/L
Cadmium, total [as Cd]	0.005 mg/L	0.00023 mg/L	0.00014 mg/L
Chromium, total [as Cr]	**0.1 mg/L**	**0.28 mg/L**	0.092 mg/L
Copper, total [as Cu]	1.3 mg/L	0.054 mg/L	0.011 mg/L
Cyanide, total [as CN]	0.2 mg/L	0.010 mg/L	0.0034 mg/L
Lead, total [as Pb]	0.015 mg/L	0.0039 mg/L	0.001 mg/L
Mercury, total [as Hg]	0.002 mg/L	0.00004 mg/L	0.00001 mg/L
Nitrate	**10 mg/L**	**>10, See discussion below**	**> 10, See discussion below**
Radiation, gross alpha	15 pCi/L	4.7 pCi/L	3.2 pCi/L
Radium 226 + radium 228, total	**5 pCi/L**	**5 pCi/L**	1.7 pCi/L
Selenium, total [as Se]	0.05 mg/L	0.0037 mg/L	0.0020 mg/L
Uranium, total [in pci/L]	30 µg/L	1.3 µg/L	1.1 µg/L

For IPR, the present analysis assumed that a surface water body would serve as the environmental buffer, rather than aquifer recharge. The specific standards for effluent that BWRF would need to meet are dependent on the receiving water body for the reclaimed water discharge. While that has yet to be definitively determined, Big Dry Creek (the receiving water for BWRF discharges) is already designated as a water supply source by CDPHE. If a different surface water body (stream or reservoir) is used as the environmental buffer, limits may differ depending on the beneficial use designations specific to that receiving water body. Even if not required by CDPHE, some form of an AWPF may be advisable, depending on system-specific circumstances.

An important parameter for potential future potable reuse operations in Broomfield is nitrate. The BWRF daily maximum discharge limit of 14 mg/L goes into effect on July 1, 2024. BWRF's Carbon Addition system came online in May 2023, and staff are operating the system as if the daily limit is in place. Further nitrate removal than historical would be required for potable reuse as the drinking water MCL is 10 mg/L; in recent months BWRF has achieved this level. Future nutrient limits on the BWRF discharge are expected to require further nitrate removal. It is likely that the Carbon Addition system in conjunction with other potential changes at BWRF will allow for nitrate levels to reach the MCL without further treatment required elsewhere. Therefore, it is assumed for this analysis that nitrate removal to meet the MCL will be achieved by the BWRF rather than in a future AWPF.

6.2.4 Anticipated Treatment Requirements and Challenges

The anticipated treatment requirements for IPR involve meeting the discharge permit conditions and the standards of the Safe Drinking Water Act. Planned process improvements at BWRF will help that facility meet its effluent requirements, including protection of Big Dry Creek as a drinking water supply source.

The anticipated treatment requirements for DPR are outlined in Section 6.2.1 of this chapter, and primarily revolve around specific technologies related to pathogen and chemical reduction. A DPR system would need multiple pathogen and chemical barriers, and the chemical barriers in particular may be subject to changing regulations as additional contaminants of concern are further regulated by CDPHE in their rules.

One likely future challenge will be PFAS removal, whether drinking water is sourced from traditional supplies, DPR, or IPR. If PFAS becomes regulated as a drinking water standard (as has been proposed at the federal level), specific treatment systems will be needed, with demonstrated effectiveness prior to inclusion in any treatment train for a potable reuse system.

6.3 Conveyance Analysis

This section describes infrastructure needs related to conveying treated effluent from BWRF to an AWPF as part of a DPR or IPR system. Existing infrastructure is not available or suitable for this conveyance. Further, Broomfield's agreement with the U.S. Department of Energy prohibits use of its non-potable reuse system for water drinking purposes.

Instead, IPR or DPR conveyance would require a dedicated pump station and pipeline to convey BWRF effluent either to an AWPF sited at the BWTF for DPR, or to a nearby receiving water body for IPR. For the purposes of this evaluation, Siena Reservoir was chosen as the assumed receiving water body, at the direction of Broomfield staff.

To size the pipe diameter, an estimate of available reusable effluent supply was needed. Broomfield provided monthly projections for 2040 of estimated reusable effluent from BWRF and non-potable system needs in an average year. The difference between these numbers represents available supply to a potable reuse project, presuming that non-potable customers would continue to be served with non-potable recycled water. These values are summarized in Table 6.3.

Table 6.3 Projected Reusable Effluent and Non-Potable Demand, 2040

Month	Reusable Effluent (mgd)(1)(2)	Non-Potable Demand, Average Year (mgd)(1)	Effluent Available for Potable Reuse (mgd)
January	6.47	0.00	6.47
February	2.12	0.00	2.12
March	0.47	0.00	0.47
April	0.83	0.54	0.28
May	1.98	2.73[3]	0.00
June	1.56	6.89[3]	0.00
July	3.85	8.99[3]	0.00
August	6.25	9.82[3]	0.00
September	6.83	6.06	0.77
October	1.89	1.61	0.28
November	7.61	0.00	7.61
December	7.46	0.00	7.46
Annual Total (MG)	**4,432**	**3,444[3]**	**2,378[4]**

Notes:
(1) Provided by Broomfield.
(2) Represents sum of Windy Gap and Colorado-Big Thompson reusable effluent estimated individually by Broomfield.
(3) This is total demand, but as shown it is expected to exceed the available reusable effluent during summer peaks, so the total reusable effluent *used* for non-potable demand is expected to be less than this value.
(4) As discussed in the prior note, not all non-potable demand can be met with reusable effluent during the summer; in those months, no reusable effluent would be available to supply a potential potable reuse system.

Ideally, every gallon of legally reusable effluent would be captured and reused. In winter, reusable supplies are high and irrigation-focused non-potable reuse demands are as low as zero. On a monthly average basis, water available in 2040 for potable reuse would occur in November, at 7.61 mgd. To provide flexibility for daily flow variability and future growth, the pump station and pipe were sized for 10 mgd, reflecting 33 percent additional capacity for daily flow variability and future growth. A 24-inch diameter pipeline was used as the basis for costing.

6.3.1 DPR Conveyance Analysis

The conveyance route for a DPR project would entail a pipeline from BWRF to a new AWPF sited at the City's WTF on West 144th Avenue. A conceptual pipeline routing runs north along Lowell Boulevard, then west on 144th Avenue. This is a total length of approximately 3.4 miles, as depicted in Figure 6.1.

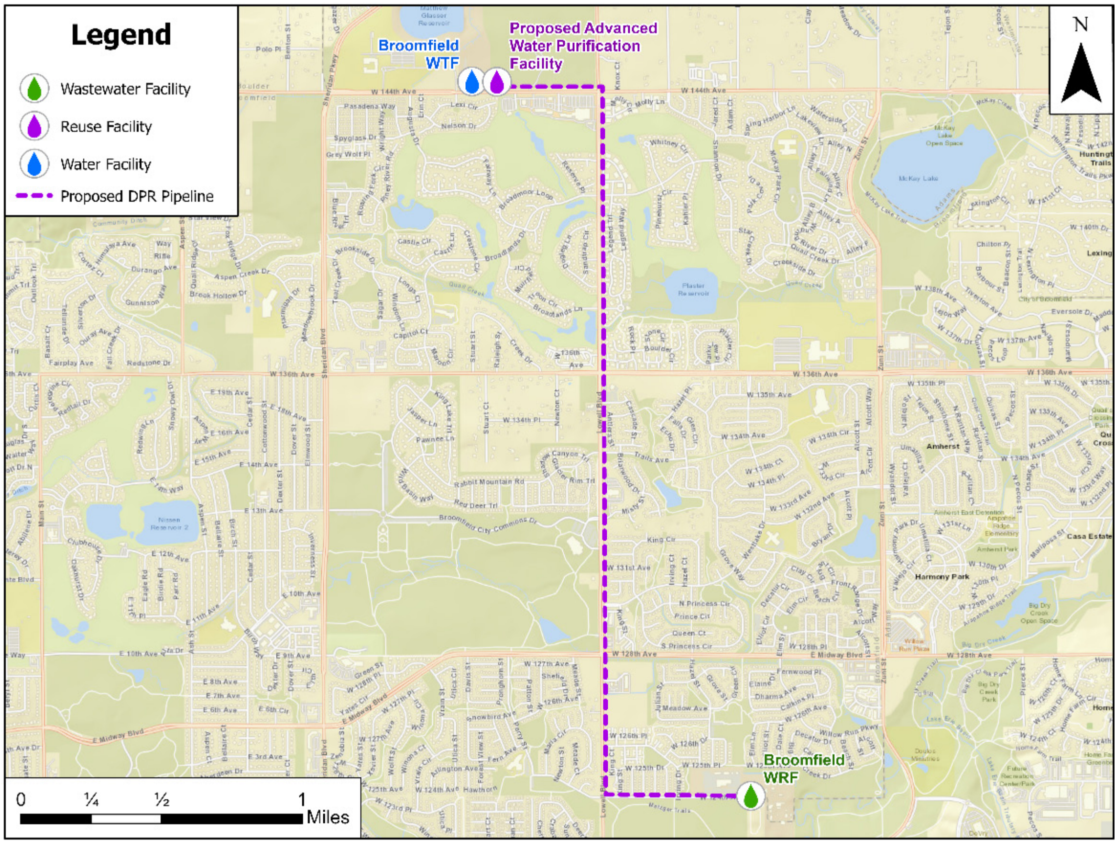

Figure 6.1 Proposed Direct Potable Reuse Conveyance

6.3.2 IPR Conveyance Analysis

The conveyance route for an IPR project would entail a pipeline from BWRF to a receiving water body as the environmental buffer. Based on input from Broomfield staff, Siena Reservoir was identified as a candidate and was assumed as the environmental buffer for IPR in this conceptual study. From BWRF, the conceptual pipeline routing runs north along Lowell Boulevard straight to the reservoir, as depicted in Figure 6.2, for a total length of approximately 4.7 miles. Because the City has already planned a pipe connection from Siena Reservoir to the WTF, infrastructure connecting the two is not included in this analysis.

This study did not evaluate storage capacity or operations at Siena Reservoir. Depending on the intended operation of an IPR AWPF, the potential for storage of reclaimed water for IPR supply would be a major consideration. For example, a storage system could buffer the seasonally available reclaimed water for potable reuse in this IPR system against constant year-round use of that supply, but this would require storage sized for capturing and holding that seasonal volume.

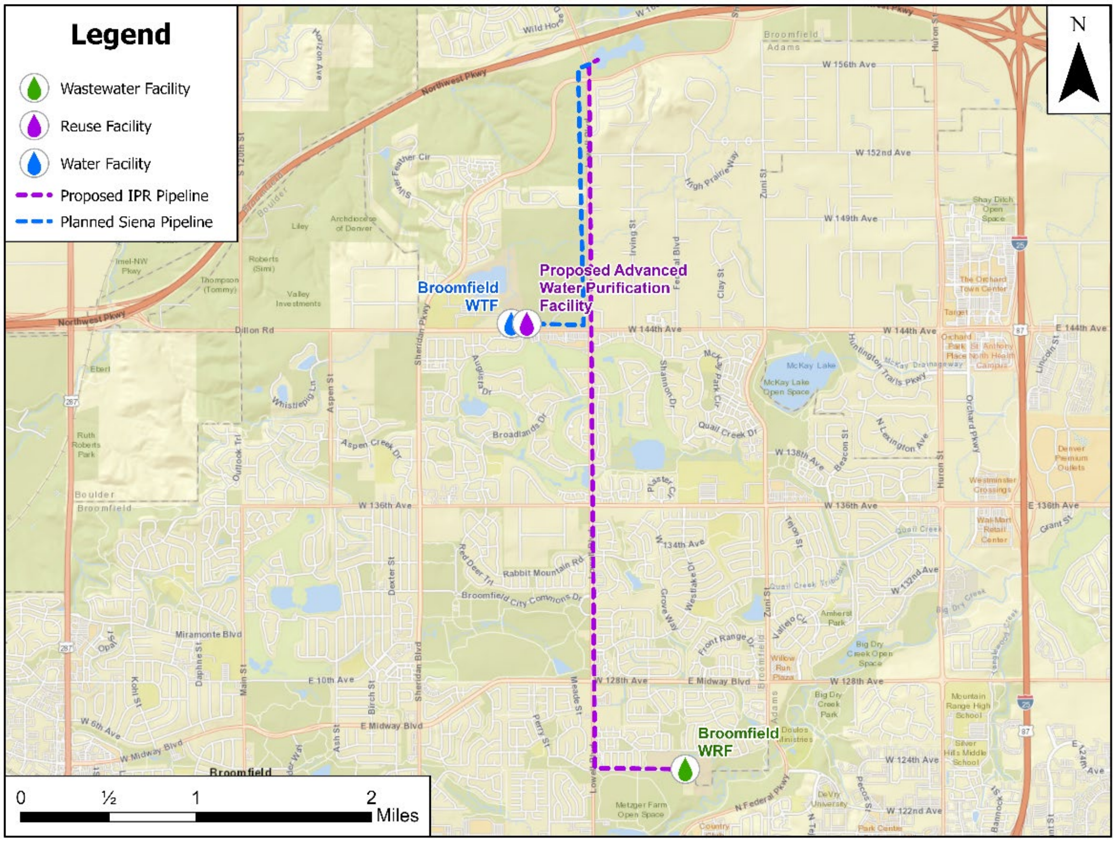

Figure 6.2 Proposed Indirect Potable Reuse Conveyance

6.3.3 Conveyance Cost Estimate

A cost estimate was developed for the conveyance alternatives using recent prices from local projects, escalated to Q4 2031 (similar to Phase 4 in the CIP). These estimates are shown in Table 6.4.

Table 6.4 Cost Estimate for Conceptual DPR/IPR Conveyance

Cost Element	Cost Basis	DPR Option	IPR Option
Pump Station (includes structure, mechanical, electrical)	Recent Industry Experience	$20,000,000	$20,000,000
24-inch Pipeline in Developed Area	$485 / LF	$8,730,000	$12,130,000
Escalation to 2031	53%	$15,230,000	$10,300,000
	Escalated Subtotal (2031 $)	**$43,960,000**	**$49,160,000**
General Conditions Labor, Expenses, and Equipment	15%	$6,594,000	$7,373,000
Builder's Risk and General Liability Insurance	1.25%	$595,000	$615,000

Cost Element	Cost Basis	DPR Option	IPR Option
General Contractor Overhead and Profit	10%	$4,396,000	$4,916,000
Performance and Payment Bond	1.10%	$484,000	$541,000
Design and Bidding Risk Contingency	30%	$13,188,000	$14,746,000
Construction Cost Subtotal (2031 $)		**$69,217,000**	**$77,343,000**
Design and Permitting	10%	$6,922,000	$7,735,000
Construction Management and Engineering Services During Construction	10%	$6,922,000	$7,735,000
Conveyance Total (2031 $)		***$83,061,000***	***$92,813,000***

6.4 Treatment Analysis

This section describes proposed treatment process trains for potable reuse. While regulations are different for DPR and IPR, ultimately the treatment process is intended to achieve the same result: water that meets requirements of the Safe Drinking Water Act. For the concept-level analysis in this study, it was conservatively assumed that the AWPF requirements for IPR would be identical to those required for DPR. It may be possible to reduce the AWPF requirements for IPR, but the limited dilution and residence time available in Siena Reservoir suggest that the AWPF differences for IPR and DPR would be minimal. In addition, discharges to Siena Reservoir in an IPR scheme should consider nutrient loading and the potential for algal growth in the feed to Broomfield's WTF.

6.4.1 Conceptual Process Train

Broomfield staff have expressed a preference for avoiding the use of RO in an AWPF due to the expense and logistical difficulties involved in dealing with the resulting concentrate. While there are RO facilities in Colorado, there are significant permitting and operational challenges associated with deep well injection of brine, stream discharge, and other brine disposal practices that have been employed at RO facilities along the Front Range. Per the previously discussed requirements of CDPHE's DPR Rule, a carbon-based advanced treatment (CBAT) treatment train could provide the required AWPF treatment.

Note that this system cannot effectively remove certain constituents such as nitrate. It is assumed that nitrate could be sufficiently removed through the recent Carbon Addition system improvements at BWRF. Pilot testing will be required to assess the removal of other drinking water parameters of concern.

To satisfy the DPR treatment requirements for AWPF, such a system could include:

- Ozonation.
- Biologically activated filter (BAF).
- Ultrafiltration (UF).
- GAC.
- Ultraviolet advanced oxidation processes (UV/AOP).

A process train schematic is provided in Figure 6.3. Such a system would remove pathogens and chemical constituents, and have lower energy-use requirements and water loss than a RO-based system.

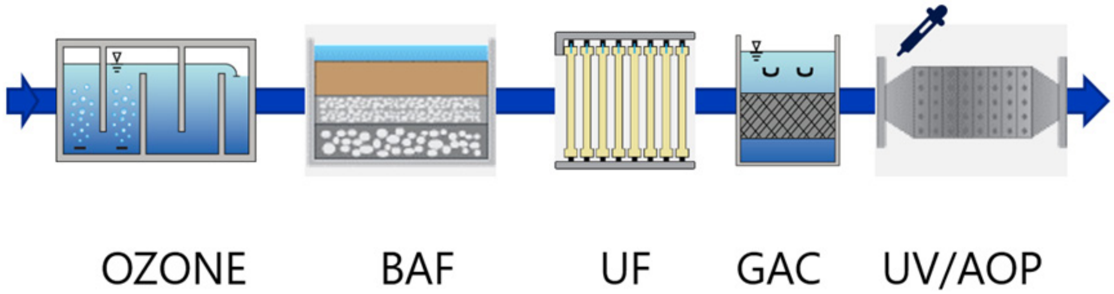

Figure 6.3 Proposed CBAT Treatment Train for Potable Reuse

6.4.2 Treatment Capital Cost

A capital cost estimate was prepared for the CBAT AWPF treatment train, using a treatment capacity of 10 mgd. Recent project costs using the CBAT treatment technologies were used to develop a cost model using unit pricing per mgd. The resulting costs for a 10 mgd CBAT-based treatment system are estimated in Table 6.5.

Note that in absence of a specific site location and a concept layout or design, these are a general starting point using estimating assumptions developed for the Wastewater Utility Plan CIP. The specific location selected will have specific design requirements that affect cost that are not known at the time of this comparative generalized estimate.

Table 6.5 Cost Estimate for CBAT-based Treatment

Cost Element	Cost Basis	Cost Estimate
Ozone Treatment	Carollo Cost Model	$2,500,000
BAF Treatment		$3,500,000
UF Treatment		$3,500,000
GAC Treatment		$9,000,000
UV/AOP Treatment		$1,500,000
	Treatment Subtotal (2023 $)	**$20,000,000**
Building Structure	$500/sf @ estimated 4,800 sf	$2,400,000
Piping and Pumping	10%	$2,000,000
Site Costs	5%	$1,000,000
Electrical and Instrumentation	25%	$5,000,000
	System Subtotal (2023 $)	**$30,400,000**
Escalation	53%	$16,112,000
	Escalated Subtotal (2031 $)	**$46,512,000**

Cost Element	Cost Basis	Cost Estimate
General Conditions Labor, Expenses, and Equipment	15%	$6,977,000
Builder's Risk and GL Insurance	1.25%	$582,000
General Contractor Overhead and Profit	10%	$4,652,000
Performance and Payment Bond	1.10%	$512,000
Design and Bidding Risk Contingency	30%	$13,954,000
	Construction Cost Subtotal (2031 $)	**$73,189,000**
Design & Permitting	10%	$7,319,000
Construction Management and Engineering Services During Construction	10%	$7,319,000
	AWPF Total (2031 $)	**$87,827,000**

6.5 Implementation Roadmap

Development of potable reuse, whether through indirect or direct means, represents an excellent way for Broomfield to help secure adequate water resources to meet the needs of its growing population. This section discusses the process by which such a project may be brought to fruition, and important questions still to be answered along the way.

6.5.1 Capital Cost Summary

The total capital cost for implementing potable reuse includes conveyance and treatment components. Since delivering recycled water from BWRF to Siena Reservoir requires a longer pipeline than delivering it directly to the WTF site, conveyance costs are higher for IPR than DPR in this conceptual analysis. For purposes of this study, treatment differences were assumed negligible between IPR and DPR. It may be possible to implement a less-intensive AWPF for IPR, which could cost less, but reducing nutrient concentrations in IPR supply prior to storing the water in Siena Reservoir (to reduce algal growth potential) could increase treatment capital costs for an IPR system. Capital costs are summarized in Table 6.6.

Table 6.6 Capital Cost Summary for IPR and DPR Systems

Cost Element	DPR (2031 $M)	DPR (2031 $M)
Conveyance(1)	$83.1	$92.8
AWPF(2)	$87.8	$87.8
Total	**$171**	**$181**

Notes:
(1) Assuming DPR is conveyed directly to WTF site and IPR is conveyed to Siena Reservoir; does not include cost of conveyance from Siena Reservoir to WTF.
(2) AWPF costs for IPR may be lower than shown, contingent on detailed analysis of water quality dynamics in the environmental buffer; additional treatment not included in these costs may be needed to further reduce nutrients prior to storage in Siena Reservoir to reduce algal growth potential.

6.5.2 Conceptual Implementation Timeline

Upon Broomfield's commitment to a potable reuse project, the next stage is to determine whether DPR or IPR will be the preferred approach. Both options have advantages and disadvantages, and the regulatory frameworks under which they are handled are different.

Regardless of the path chosen, some elements remain common, and the opportunity exists to change from DPR to IPR or the reverse if it is found to be preferable. As an example, the City of Wichita Falls, Texas, implemented a DPR system in response to an intensive drought, but later reverted to IPR (augmenting a surface water supply source) when drought conditions eased and lake levels recovered.

1. **Detailed wastewater characterization and development of an enhanced source water control plan** is the first step. A detailed breakdown of all potential contaminants of concern currently found in BWRF effluent will enable the process of identifying potential sources of constituents of concern in the wastewater collection system and reducing or eliminating them, along with the development of an ongoing monitoring plan to maintain compliance with DPR and water quality regulations. It is estimated that development of this plan will take 24 months; 6 months to develop the source control plan, 6 months to implement it to the level required by CDPHE for DPR projects, and 12 months of activity to achieve the goals of the plan prior to taking the next step to ensure adequate BWRF effluent quality.
2. With source control in place, **pilot testing** of chosen technologies can begin, to allow for demonstrating effectiveness of these technologies with BWRF effluent as required by CDPHE for DPR projects and as would be desired by the public for any potable reuse effort. It is anticipated this step will take 18 months: 6 months to set up pilot testing, and 12 months of pilot testing. The setup may run concurrently with the last phases of enhanced source control.
3. With successful pilot testing at least partially completed, **public outreach** can begin in earnest, as the relevant treatment trains will be identified and can be presented to the public, keeping them "in the loop" with results as testing progresses. This should continue but will likely begin with an initial presentation to Broomfield's City Council, followed by public presentations about the plans for potable reuse and a timeline for implementation. This will likely require 6 months of planning prior to presenting materials to the public.
4. Simultaneous to public outreach, **preliminary design** (including alternatives analysis) can begin on a full-scale facility, as this will inform a detailed cost evaluation to be used when seeking funding. This is anticipated to take 12 months, some of which can coincide with the piloting effort once sufficient results are available to inform design.
5. With public engagement underway and preliminary design producing cost estimations - and with well-developed public support – Broomfield can begin seeking **funding and financing for full-scale project development**. A variety of funding sources exist to help with innovative projects such as DPR and IPR. This is anticipated to take 12 months.
6. Finally, the project can proceed to **final design and construction**. With a well-developed preliminary design, this is estimated to take 24 to 36 months, including conveyance and treatment.

Some of the steps described above are required for DPR, giving stricter guidance on exactly what each entails in line with CDPHE's DPR Rule. That rule, though not legally applicable to IPR projects, can provide a framework for such projects as well. The regulatory section earlier in this document provides a detailed overview of this rule.

A graphic representation of the steps and estimated timeline for implementing a potable reuse program is shown in Figure 6.4. This represents an aggressive implementation strategy with minimal schedule buffer. Should any step(s) take longer than indicated for this accelerated pace, the overall timeline would be extended accordingly.

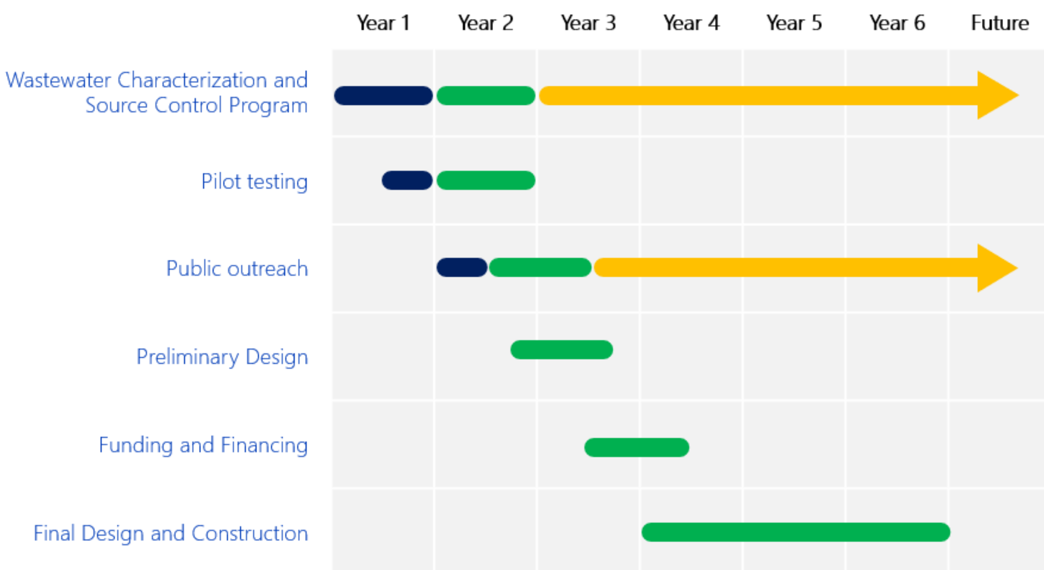

Figure 6.4 Steps Towards Potable Reuse Implementation and Estimated Timeframe

6.5.3 Challenges and Recommended Next Steps

Advancing through the previously described steps still holds several challenges for Broomfield. Recommended next steps include:

- Expanding and staffing a robust pretreatment program to form an enhanced source control program, as many other entities interested in potable reuse and source control are doing, leading to competition for staff and resources.
- Making the case for pursuing a potable reuse project to key stakeholders in appointed/elected leadership; this will be a major undertaking and will require cohesion that is challenging to achieve in any organization.
- Identification of key champions at the operational level for both water and wastewater who can work with their teams to bring this project to fruition, as they will need to coordinate extensively throughout the project development period.

- Initiation of community engagement programs to build understanding of the need for potable reuse and its regulatory and operational safeguards, toward increasing community awareness and support for the project.
- If IPR is selected as the preferred potable reuse option, identification of an appropriate receiving water body to serve as the environmental buffer (potentially with storage), and planning for the acquisition and/or additional development of this receiving water body as needed.

As Broomfield progresses through these initial steps, the larger project picture and timeframe will begin to come into focus, allowing for detailed planning of expenditures and efforts to bring potable reuse to Broomfield if it decides to pursue a DPR or IPR project.

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Chapter 7

RECOMMENDATIONS FOR BWRF IMPROVEMENTS

Previous chapters in this Wastewater Utility Plan document regulatory requirements, current and projected flows and loads through the planning horizon, unit process treatment and hydraulic capacity, process control improvements, condition assessment, process optimization, and treatment alternatives. Those chapters build the framework for future planned improvements to the BWRF.

This chapter summarizes the recommended improvements for the BWRF that were described in previous chapters. Projects identified in previous chapters are included and arranged into larger groupings according to the type of project, the proximity of projects, similar schedule drivers, and the criticality of project interdependencies. Grouping several smaller projects into a few larger projects (referred to as "phases" in this document) benefits Broomfield in the following ways:

- Reduces administrative efforts associated with procurement and management functions.
- Improves coordination between fewer contractors and engineers and allots fewer points of responsibility.
- Allows for coordination of improvements to minimize interruptions of facility operations.

This chapter reviews the planning and design approval process, explains the grouping and prioritization of projects, reviews scheduling and estimating assumptions, and summarizes the recommended CIP.

7.1 Planning and Design Approvals from Others

The following sections identify potential permitting steps that may be required depending on how the projects are implemented and the regulatory agencies involved.

7.1.1 Site Location Approval

A Site Location Approval from CDPHE is required to construct a new domestic wastewater treatment facility, increase design capacity of wastewater treatment works, change unit processes, and replace assets. This approval process requires the submittal of an engineering report, which must include detailed definitions of the treatment improvements and evaluate how those changes will affect the facility. The engineering report is typically developed during the preliminary design phase and submitted to CDPHE with figures and justifications for requesting the approvals. Water Quality Planning Targets or a Preliminary Effluent Limitations (PEL) document may be needed in the future if the facility's rated capacity changes due to increased flow and loading conditions. These planning targets may be the first part of the Site Location Approval process to expand future treatment capacity.

7.1.2 Chemical Approval

CDPHE requires approval of any proposed chemical through a chemical evaluation process including whole effluent toxicity testing of the proposed chemicals. Currently, CDPHE is not granting chemical approvals for facilities with expired permits that have been administratively extended by CDPHE. The permit for the BWRF expires in December 2024. Therefore, early in the design approval process for these initial projects, Carollo recommends consideration of chemicals needed in the coming projects and determination of whether to proceed with chemical approval.

7.1.3 Design Approval

The Design Approval from CDPHE is typically received after the Site Location Approval and before construction activities commence. Design approval requires the submittal of design drawings along with a Process Design Report (PDR) to the CDPHE for review and approval. The PDR must contain the required information as indicated in Policy WPC-DR-1 Design Criteria for Domestic Wastewater Treatment Works.

Once Site Location and Design Approvals are received from the CDPHE, construction activities can begin. These approvals are usually received during the design phase. The approval durations should not significantly affect the schedules provided in this chapter if approvals are submitted in a timely fashion. Current approval timelines for both site location and design approval are in the 3- to 6-month range.

7.2 Procurement Approaches

Broomfield may use the following procurement approaches to deliver recommended capital improvement projects.

- Self-Perform: Work activities that are performed solely by WRF staff. This could be used in the planning and design phases or considered for small construction projects. This could include asset replacement projects.
- Design-Bid-Build (DBB) Procurement: The traditional approach of using an engineer (internal or external) to complete the design and bidding phases and then hiring a third-party contractor to construct the facilities.
- Construction Management at Risk (CMAR) Procurement: An alternative delivery method in which the construction manager participates early in the design phase to provide constructability and estimate support. The Owner still holds separate contracts with the Engineer and the CMAR Contractor.
- Design-Build (DB) Procurement: An alternative delivery method in which the DB team completes the design and construction as one functional team. The Owner holds the contract with the DB team, which could be the Engineer or the Contractor depending on how the team is structured.
- Public-Private Partnership (P3): Revenue-generating projects such as the beneficial reuse of biogas can be delivered via a P3 model. A private entity funds the capital expenses in return for the revenue from the sale of biogas and renewable energy credits.

All of the larger projects could be completed using DBB, CMAR, or DB. However, to make scheduling and budget decisions, the CMAR procurement approach was assumed. On a project-by-project basis, Broomfield may elect to use another procurement approach that creates the best value for the organization.

As projects are packaged, Broomfield should consider other procurement strategies that provide value for the organization such as the following:

- Pre-purchase or pre-select equipment based on a best value selection process. Equipment is selected based on competitive pricing, which includes capital and operating costs in addition to non-economic considerations.
- Pre-qualify general contractors and subcontractors. This allows only qualified applicants to submit bids for the project. This should be considered for larger projects.

7.3 Project Groupings and Phasing

The improvement projects from the previous chapters were combined into a prioritized CIP. Table 7.1 summarizes the project phases, components, and drivers for the CIP by phases. The following sections describe each project phase in more detail.

Table 7.1 Project Groupings and Phasing

Phase	Components	Drivers
1	Flow Equalization, Liquids Odor Control, Blower Upgrades, Solids Handling Site Preparation	Liquid Stream Optimization and Asset Renewal, Site Preparation for Solids Handling Improvements
2	Solids Handling Improvements, Fourth IFAS Train, North and Middle IFAS Train Improvements, Biogas Utilization, Centrate Equalization and Sidestream Nitrogen Treatment	Solids Operation and Performance, Liquid Stream Load Capacity, Resource Recovery, Effluent Nutrient Compliance
3	UV and Reuse Filtration Expansion, South IFAS Train Upgrades, Sidestream Phosphorus Treatment, PFAS Treatment, Generator Improvements	Liquid Stream Load Capacity, Reuse Objectives, Asset Renewal, Effluent Nutrient Compliance, Regulations
4	Hydraulic Capacity and Asset Improvements, Solids Loadout Improvements, Temperature Compliance	Hydraulic Capacity, Asset Renewal, Process Efficiency, Regulations
5	Regulation 31 Compliance	Regulations

7.3.1 Phase 1 Project

The Phase 1 project consists of the following major components:

- Covered equalization tankage and pumping in the northwest corner of the site, relocated from the southwest corner. One equalization tank to serve as a future primary clarifier.
- New liquids stream odor control system.
- Blower and aeration process control optimization for the existing north IFAS reactors.
- Replacement of Secondary Clarifier Mechanisms 3 and 4.
- Upgrades to reuse pumping system.
- Site preparation for construction of solids handling improvements.

The **driver** for this phase is to accelerate preparations for the larger Phase 2 project by relocating the open-air equalization volume and end-of-life equalization pumping closer to other liquids stream processes, while allowing improved odor control treatment. The space for the current equalization basins will be used for the solids handling improvements in Phase 2 and for future sidestream treatment and effluent cooling technologies in Phases 3 and 4. This project phase is a key construction sequence component for initiating the overall CIP.

Site layout and components of the Phase 1 project are shown in Figure 7.1.

7.3.2 Phase 2 Project

The Phase 2 project consists of the following major components:

- Construction of a fourth secondary treatment train on the north side of the facility site.
- Replacement of the existing K1 IFAS media with K5 media in the north and middle trains.
- Primary sludge pump replacement.
- New solids stream odor control system.
- Construction of new solids thickening and digestion systems, including:
  - Two DAF tanks and a DAF support mechanical facility.
  - TWAS and primary sludge blend tank.
  - New anaerobic digester complex.
  - Beneficial biogas use system.
- Dewatering upgrades, including:
  - Centrifuge replacement.
  - Centrate flow equalization.
- Sidestream nitrogen treatment.
- Asphalt paving on plant roads.

For the liquid stream, the **driver** of this project phase is to increase treatment robustness and redundancy under the current permitted capacity. While the south IFAS train can be utilized, it remains offline due to asset age and operational challenges. Operations staff have noted several key structural and operational concerns with the IFAS reactors and their two relatively shallow secondary clarifiers, and the preference is to leave this train out of service unless needed for emergency purposes. Without this train in service, the north and middle IFAS trains operate near their rated capacity under current flows and loads based on process modeling. Therefore, construction of the fourth secondary treatment train is required for meeting the current rated capacity of the facility and for sequencing improvements in the existing north and middle trains (assuming the south train remains offline until Phase 3). With the proposed media replacement in the north and middle trains and construction of the fourth secondary treatment train in Phase 2, Carollo estimates that the facility may reach permitted capacity between approximately 2030 and 2033 without operating the south train.

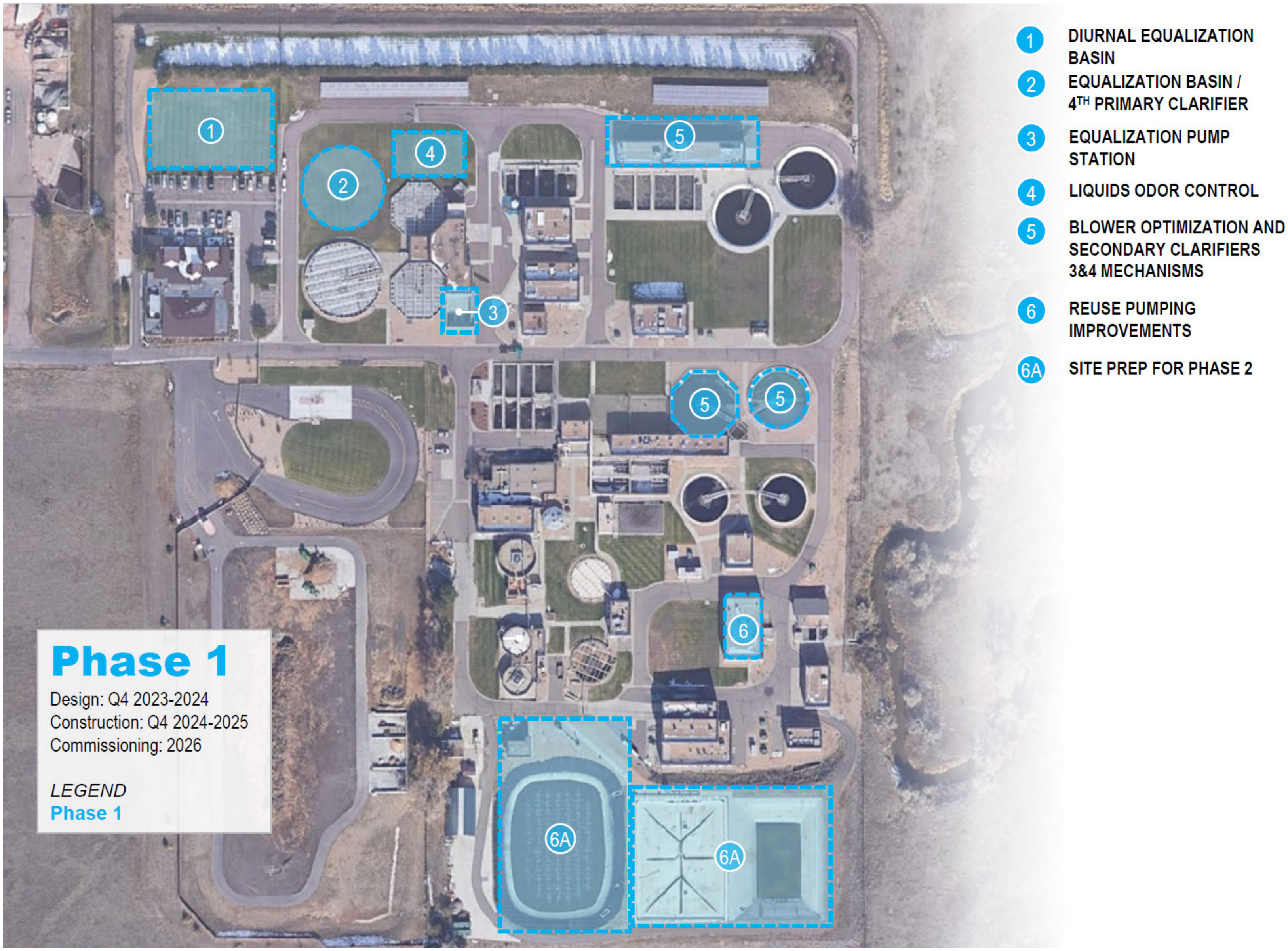

Figure 7.1 Phase 1 Project – Site Layout and Components

For the solids stream, most all of the solids thickening and digestion equipment has reached the end of useful life and lacks sufficient redundancy to maintain resilient operation into the future. Furthermore, the current anaerobic digesters lack the capacity to achieve full digestion, which limits the facility's beneficial biosolids and biogas use opportunities. The Phase 2 recommended improvements are sized to provide the facility with sufficient thickening and digestion capacity for achieving Class B biosolids through Broomfield's current estimated buildout population (see Chapter 1). Capital funds and site footprint for beneficial use of biogas from the anaerobic digesters are included. Expanded centrifuge dewatering capacity (within the existing Solids Processing Building) and new centrate equalization volume and pumping sized for the current estimated buildout population are also included.

It is likely that centrate nutrient strength (both nitrogen and phosphorus) will increase as compared to historical nutrient recycle loads after the new anaerobic digesters are brought online. This added nutrient recycle load back to the liquid stream could increase the risk of effluent permit compliance with Regulation 85 and the forthcoming daily maximum TIN limit. Furthermore, it may result in increased dependence on external carbon addition for achieving sufficient denitrification in the unaerated zones. As such, Carollo recommends reserving site footprint and capital budget for installing sidestream nitrogen treatment (e.g., ANITA™ Mox) of the centrate. A **key decision point** for inclusion of sidestream nitrogen removal will be during conceptual design of Phase 2, during which the design consultant and Broomfield can re-evaluate the need to include sidestream nitrogen removal based on:

- Impacts of improved aeration control on denitrification performance in the existing secondary treatment process.
- Estimated external carbon demand required for meeting the daily maximum effluent TIN limit with and without sidestream nitrogen removal.
- Improved process modeling accuracy and resolution, resulting from special sampling of the influent, to better characterize the potential centrate nutrient loads resulting from improved volatile solids reduction in the digestion process.

If Broomfield and the design consultant find that the liquid stream process can reliably treat the increased centrate nitrogen load without compromising effluent compliance with Regulation 85 or the daily maximum TIN limit, then Broomfield may choose to postpone sidestream nitrogen treatment to a later phase in preparation for Regulation 31.

It is unclear at this time how much the recycled centrate phosphorus load may increase and if the resulting load will have a significant impact on effluent total phosphorus. This is predominantly due to the presence of metal hydroxide sludges received from the Broomfield Water Treatment Facility and due to onsite ferric addition for odor control, which effectively bind a significant portion of soluble phosphorus throughout the facility. While ferric hydroxide sludges can be reduced in the digesters, leading to release of bound soluble phosphorus, aluminum hydroxide sludges from the water treatment facility will likely remain unchanged. As part of Phase 2, Carollo recommends that the facility include provisions for dosing of metal salts (e.g., ferric) at solids handling and in the secondary treatment process to polish effluent phosphorus as needed. Capital costs and site footprint are reserved for sidestream phosphorus treatment (e.g., MagPrex) in Phase 3 or in subsequent phases, if Broomfield finds it necessary to construct.

Site layout and components of the Phase 2 project are shown in Figure 7.2.

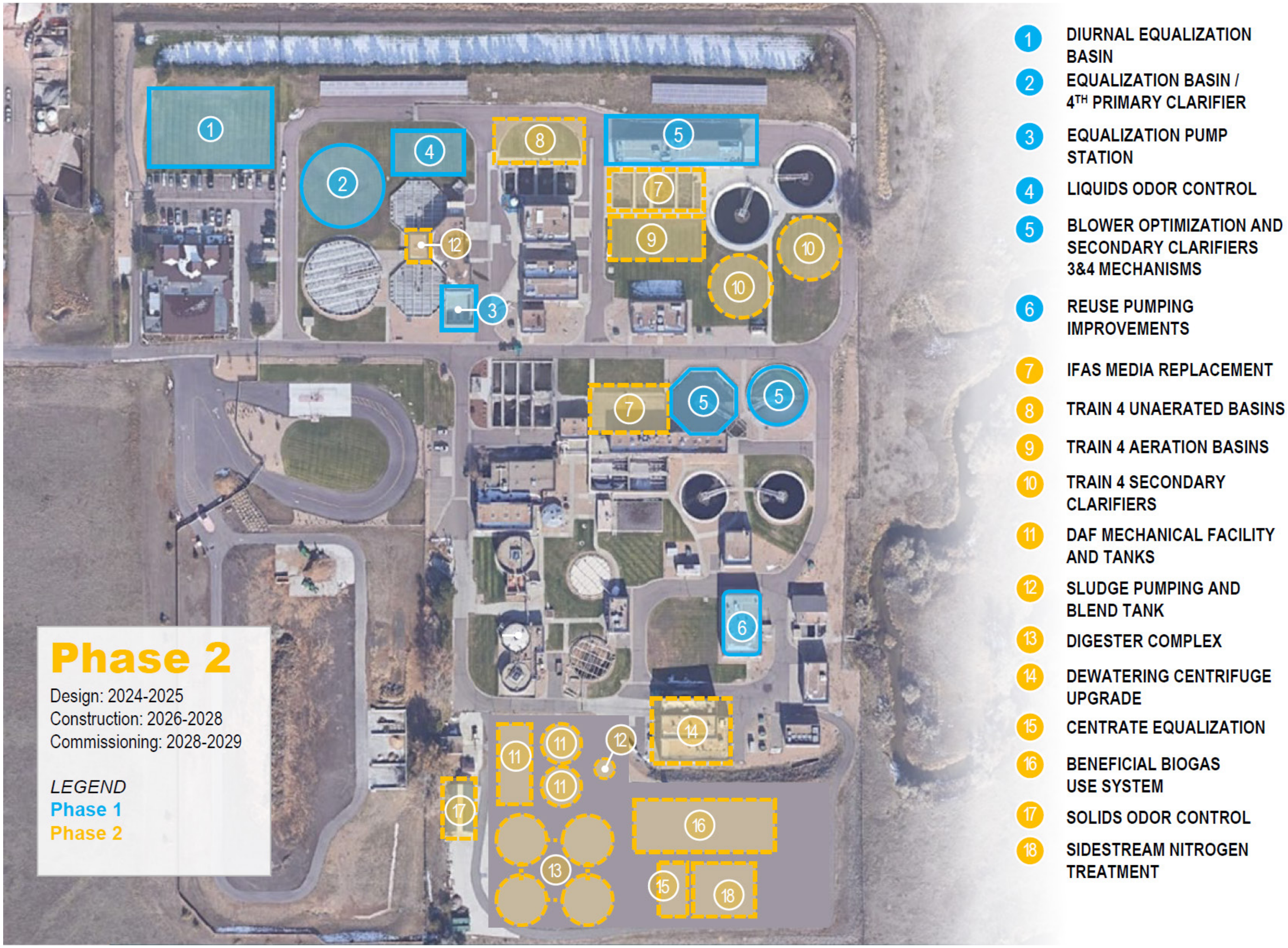

Figure 7.2 Phase 2 Project – Site Layout and Components

7.3.3 Phase 3 Project

The Phase 3 project consists of the following major components:

- Improvements to the existing backup generator buildings and equipment.
- Demolition and replacement of the south train IFAS reactors and two secondary clarifiers.
- Demolition of the existing south/middle train IR pump station and construction of a new pump station.
- Demolition of the odor control facilities adjacent to the south train IFAS reactors.
- Expansion of the UV system for meeting future projected flows.
- Expansion of the existing filtration facility for non-potable reuse.
- Sidestream phosphorus treatment (if necessary, based on process performance after Phase 2).
- Site preparation focused on demolition in the area of the existing digesters and sludge holding tanks.
- Liquid stream PFAS treatment.

The **driver** for this project phase is to provide sufficient liquid stream treatment capacity and redundancy with four operational secondary treatment trains and expanded UV disinfection such that the facility can be re-rated for meeting future flows and loads through the planning horizon. The **key decision point** for rebuilding the south train IFAS reactors and secondary clarifiers is projected population growth; based on information provided in Chapter 1, the facility will reach permitted load treatment capacity by approximately 2031, triggering the need for expansion.

Site footprint and capital budget are reserved for constructing sidestream phosphorus treatment, if necessary, based on recycled nutrient loads resulting from Phase 2 improvements (**key decision point**). Reuse filtration expansion is driven by reuse system needs and demands. A **key decision point** for reuse filtration expansion will be the timing that Broomfield wants this expanded capacity online for reuse system needs.

The **driver** for the described site preparation is future PFAS regulations, which remain unclear at this time. The **key decision point** for scheduling interior site demolition will be based on the facility's next permit renewal(s) and Broomfield's available capital budget. Site preparation cannot occur until after other Phase 3 improvements are completed (due to sequencing and treatment requirements) but are not necessarily required until the scope and timing of PFAS and Regulation 31 improvements are more clear.

Currently, regulatory timing and approach are the **key decision points** for PFAS treatment of the effluent and/or biosolids. Carollo recommends that Broomfield continue to proactively monitor and remain engaged in regulatory discussions as it relates to PFAS. For the sake of planning, a placeholder capital cost and site footprint for an unknown future PFAS treatment system are included herein. Draft drinking water standards for PFAS published by the EPA in March 2023 may accelerate timing of regulatory limits.

Site layout and components of the Phase 3 Project are shown in Figure 7.3.

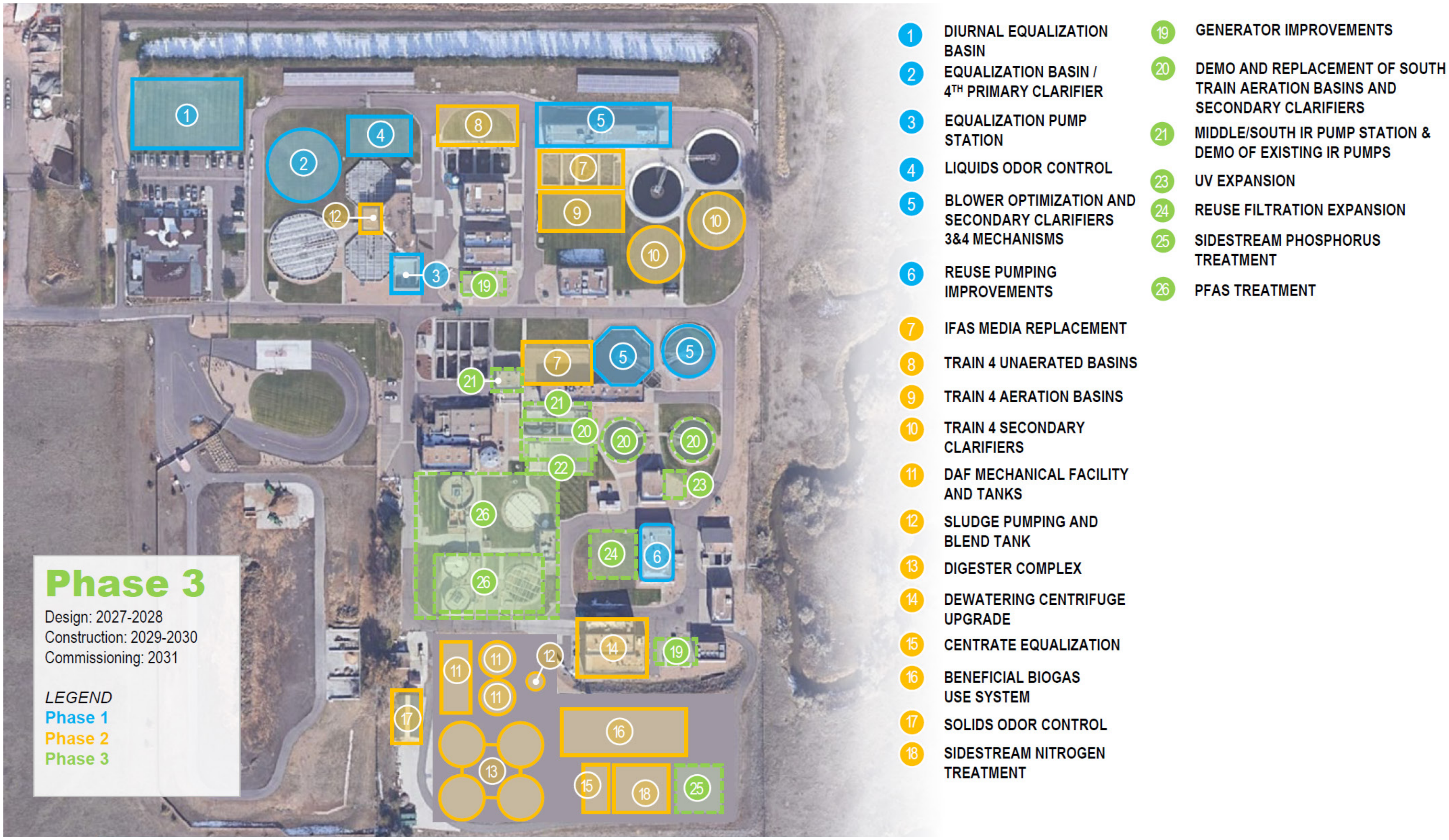

Figure 7.3 Phase 3 Project – Site Layout and Components

7.3.4 Phase 4 Project

The Phase 4 Project consists of the following major components:

- Hydraulic capacity and asset improvements at preliminary and primary treatment.
- New solids loadout facility at the existing Solids Processing Building.
- Installation of effluent cooling towers.
- Concrete paving on plant roads.

The **drivers** of the liquid stream improvements are rated hydraulic capacity and compliance with future regulatory requirements for effluent temperature. Hydraulic improvements at preliminary and primary treatment, both in flow conveyance and equipment sizing, will be required for re-rating the hydraulic capacity of the facility beyond the current rating of 12 mgd ADMMF (31.2 mgd PHF). The **key decision point** for these improvements will be the rate of future population growth as compared to the projections summarized in Chapter 1. Based on the best available information provided by Broomfield, this re-rating likely will be required between the years 2033 and 2035.

The **key decision point** regarding effluent temperature will be the facility's next permit renewal. Based on the regulatory review presented in Chapter 1, the facility should plan for temperature limits within the next permit renewal cycle, with implementation occurring sometime in the early 2030s. It should be noted that previous permit renewal cycles generally occurred at regular 5-year intervals; however, renewals have fallen behind, and longer periods between permit renewals frequently occur. Therefore, it is likely that effluent temperature compliance will not be required in the facility's permit until after approximately 2033. Regardless, in case CDPHE does renew the permit on schedule in 2025 and gives Broomfield a 5-year compliance schedule for temperature, the facility should be prepared to pull this project forward into Phase 3.

The **drivers** for the solids loadout facility are cost and operational efficiency. The facility currently discharges dewatered biosolids produced by the centrifuges directly into a truck trailer. Broomfield must pay to lease the trailer while it is being filled and must stop dewatering operations when it is full to allow the trailer to be moved and replaced. The installation of either hoppers or silos to store multiple days' worth of biosolids between the centrifuges and the loadout trucks would minimize the time Broomfield needs to lease the trailers (the trailers would only be for loading and not also storage) and enable continued solids processing while trucks are full and moving.

Site layout and components of the Phase 4 project are shown in Figure 7.4.

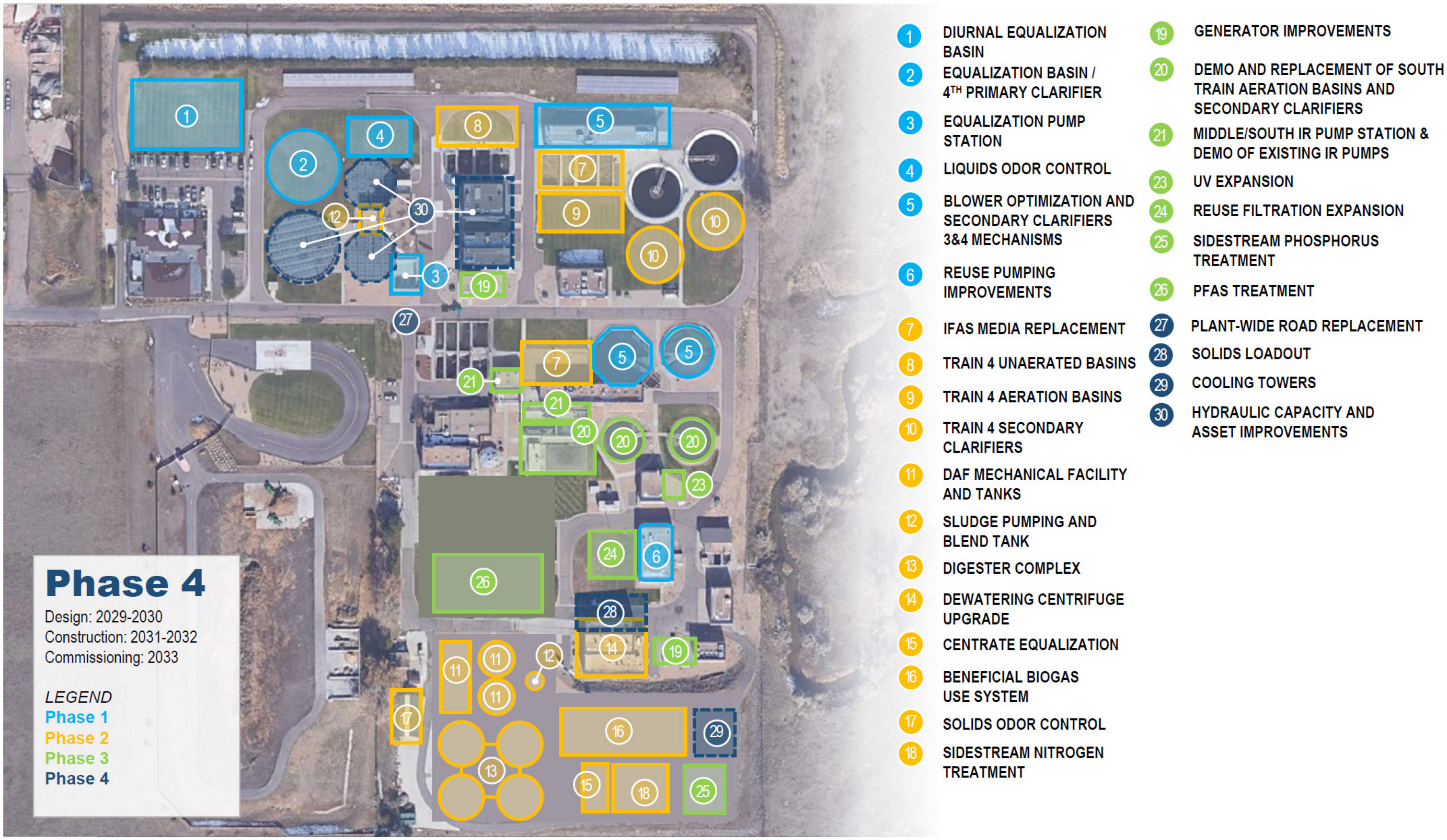

Figure 7.4 Phase 4 Project – Site Layout and Components

7.3.5 Phase 5 Project

The Phase 5 project consists of the following major components:

- Construction of liquid stream treatment improvements for compliance with Regulation 31 effluent nutrient limits.

As noted above, the **driver** for Phase 5 is future regulatory limits that will not become effective until at least the late 2030s. For the liquid stream improvements, compliance with the interim Regulation 31 effluent limits at end of pipe could necessitate RO treatment in the future; however, there are preliminary discussions occurring at the utility, consultant, and regulatory levels about the cost and environmental implications of requiring RO treatment at inland wastewater facilities. Broomfield also could consider the option of diverting all effluent flow for reuse rather than discharging to the Big Dry Creek, which at this time would appear to result in less stringent effluent nutrient limits as compared to Regulation 31. As such, **the key decision point** for Regulation 31 liquid stream improvements will be based on Broomfield's future path towards meeting non-potable and potentially potable reuse demands weighted against the effluent nutrient requirements, which are anticipated to be finalized after 2027. For the sake of planning, capital cost and site footprint for tertiary denitrification and phosphorus filters are included herein. Carollo recommends revisiting this recommendation after 2027, once the interim Regulation 31 limits are finalized and Broomfield's future reuse goals defined.

Site layout and components of the Phase 5 project are shown in Figure 7.5.

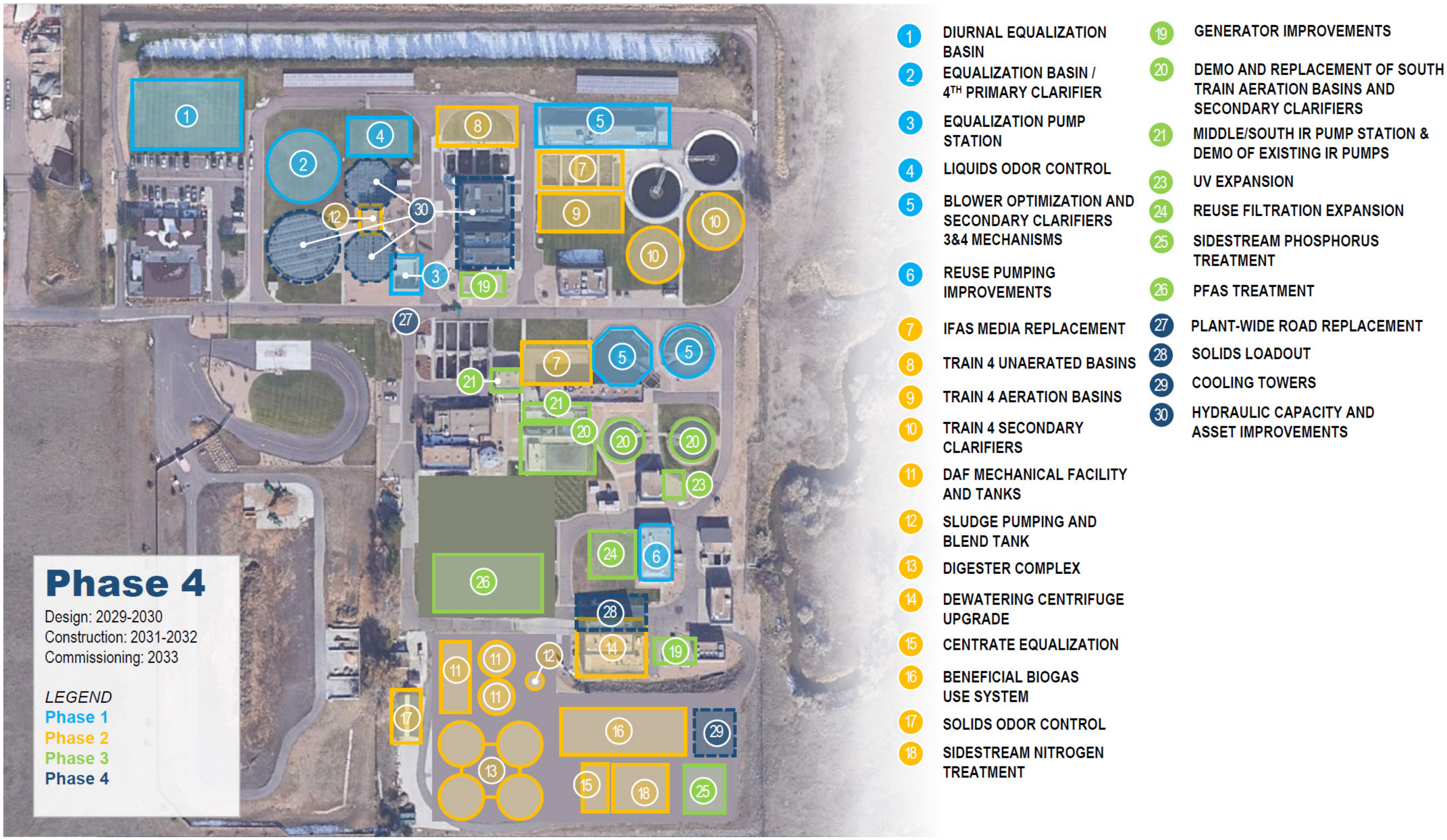

Figure 7.5 Phase 5 Project Site Layout and Components

7.4 CIP Schedule

Each project requires procurement, design, permitting, construction, and an operational startup or commissioning period. These schedule assumptions are defined in each project and affect the total duration of each project.

A preliminary schedule of the proposed projects has been developed based on the drivers for each project. Specifically, these projects are scheduled based on flow and load capacity needs, asset renewal and upgrades, and anticipated timing of regulatory requirements. The proposed preliminary schedule, pending key decision points and adjustments, is shown in Table 7.2. The schedule, including key permitting requirements and timelines, is shown in Figure 7.6.

Table 7.2 Proposed CIP Schedule

Project Phase	Design	Construction	Commissioning	Key Considerations
1	Q4 2023-2024	Q4 2024-2025	2026	Site Preparation for Solids
2	2024-2025	2026-2028	2028-2029	Capacity Drivers, Performance, Resource Recovery
3	2027-2028	2029-2030	2031	Timing of Load Growth, Asset Upgrades, Reuse Approach, Timing of PFAS Limits
4	2029-2030	2031-2032	2033	Timing of Flow Growth, Treatment Approach, Temperature Limits
5	2035-2036	2037-2038	2039	Timing of Regulation 31 Limits and Approach to Treatment/Reuse

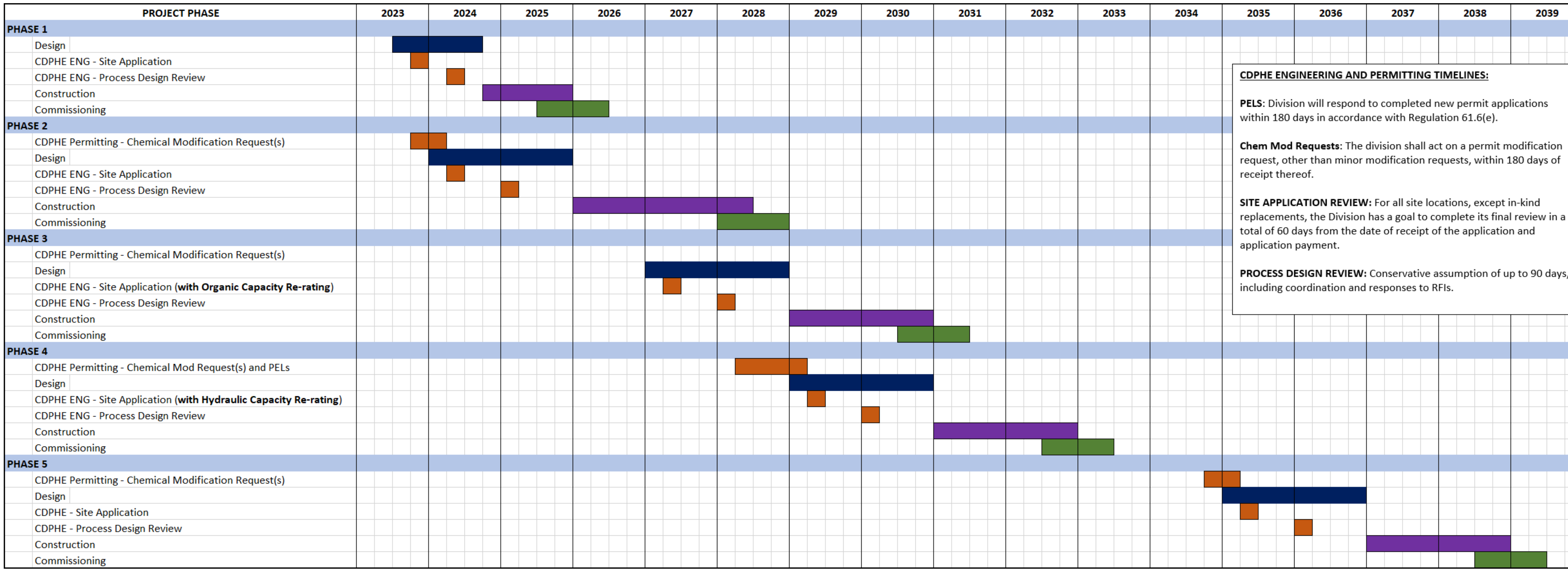

Figure 7.6 Schedule of Projects and Permitting Requirements

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7.5 Construction Sequence and Constructability

Planning level considerations for construction sequence, constructability, and delivery of these projects are summarized in the following sections.

7.5.1 Overall Site Construction Considerations

Based on the existing constraints of the BWRF property lines, there will be very limited space for construction of the new and modified facilities. The laydown areas necessary for construction will be in very short supply. To increase the efficiency of the construction projects and reduce potential costs of the projects, it is recommended that Broomfield coordinate access with the Broomfield Park Maintenance facility located to the west of the BWRF to allow for contractor staging. It is understood that the City of Westminster's adjacent Metzger Farm Open Space Park area is not available for leasing or use for construction staging.

While the amount of earthwork may seem minimal on site, without having space on site to stage soil stockpiles for reuse of excavated soils, the Contractor will have the additional cost of directly exporting material during excavation, as well as the cost of importation of material for backfilling newly constructed facilities. Having the ability to utilize parts of the adjacent tree recycling and mulch area could help in lowering overall costs even when the cost of rehabilitation of the area is considered. It is anticipated that the additional laydown area within the Broomfield Park Maintenance facility would be necessary at least through Phases 1 through 3. While project scope is very preliminary regarding Phases 4 and 5, it would be anticipated that the existing Broomfield Park Maintenance facility would continue to be necessary to facilitate construction of those projects. However, until project designs are completed for later phases, the detailed site construction considerations cannot be fully anticipated.

7.5.2 Phase 1 Project Construction

As noted previously, one of the key drivers of Phase 1 is to create available space at the southside of the facility for larger capital improvements associated with Phase 2. With most of the work revolving around new concrete equalization basins, it is not anticipated that the current supply chain issues affecting construction will affect procurement of materials for Phase 1. It is anticipated that the Contractor will be able to work concurrently on the equalization basins, liquids odor control system, and blower optimizations leading to an overall Phase 1 project duration of approximately 14 months. As noted above, having the ability to utilize the Broomfield Park Maintenance yard will assist greatly in the sequencing of the work and staging of the material. Sequencing blower, secondary clarifier, and reuse pump improvements will require coordination with plant operations staff.

7.5.3 Phase 2 Project Construction

Phase 2 entails a substantial amount of capital improvements with the construction of the fourth secondary treatment train, as well as the solids handling units to be located at the south side of the facility. MCC and PLC improvements are anticipated as part of Phase 2, and due to long lead times associated with these items, their early procurement may be necessary during design in order for construction to sequence appropriately. Staging of materials would continue to be an issue within the BWRF footprint and continued utilization of the Broomfield Park Maintenance yard would be strongly recommended to help facilitate construction activities. Due to the scope and size of Phase 2 elements, it is anticipated its duration would be at least 24 to 30 months, and possibly longer given the magnitude of the work and procurement timeframes.

7.5.4 Phase 3 Project Construction

Phase 3 entails the complex demolition and replacement of the south train IFAS reactors and secondary clarifiers. As previously noted, the existing south train IFAS basins are in poor structural condition, and it would be recommended to shift the basins to the south in lieu of attempts to rehabilitate the existing ones. This will entail complex sequencing in demolishing and preserving parts of the existing south train basins while the new basins are constructed. Additionally, generator improvements are recommended to provide a more robust redundancy system for the plant operation. Depending on the status of the global supply chain, early procurement of generators and associated switchgear equipment may be necessary to avoid delays during construction. Early procurement of generator equipment should be evaluated early in the design phase of Phase 3. It is anticipated that many of the elements of construction for Phase 3 can be constructed concurrently with an anticipated construction duration of 18 to 24 months.

7.5.5 Phases 4 and 5 Projects Construction

It is anticipated Phase 4 construction will take place in 2031 to 2032 while Phase 5 construction is anticipated in 2037 to 2038. The overall scope of Phases 4 and 5 involves a smaller footprint within the BWRF than the other phases; however, it would be anticipated that the Broomfield Park Maintenance yard will continue to be utilized for construction laydown areas. As these project scopes are extremely preliminary at this time it would be beneficial to reassess the utilization of additional laydown areas prior to their construction.

7.6 Project Cost Estimates

Project cost estimates (also known as opinions of probable cost) were prepared for each phase. The estimates were prepared at the master planning level using pricing from similar projects, initial facility layout concepts, conceptual unit cost factors, available vendor quotes, equipment pricing, historic pricing databases, and knowledge of typical rates for local construction crew by Carollo's cost estimating team. It is important to realize that changes (to scope, phasing, components, and project delivery approach) will alter the totals to some degree and that future changes in the cost of material, labor, and equipment can affect the total. All cost estimates developed represent the Association for the Advancement of Cost Engineering (AACE) International criteria for a Class 5 Planning Level or Design Technical Feasibility Estimate. For this class of estimate, the accuracy is typically -50 to + 100 percent. The accuracy of any cost estimate may change according to the design, mobilization, economies of scale, and project phasing.

The estimates were prepared by Carollo's cost estimating team using Sage Estimating software and include direct and indirect construction costs intended to replicate the pricing approach of a general contractor.

Direct labor and equipment costs were calculated by applying the hourly cost of various crews comprised of labor and equipment resources to an anticipated production rate based on the perceived level of effort. Labor and equipment rates were updated and localized to best reflect current market conditions. Project-specific quotes were used for major material purchases and process equipment items when available. Historical pricing data was referenced as necessary.

A procurement strategy was applied to the direct costs to replicate the contracting approach commonly used by general contractors. Specifically, distinctions were made within the estimate to identify work that would be self-performed, subcontracted, or provided by a vendor as each scenario contains its own unique set of mark-ups.

Indirect costs such as builder's risk and general liability insurance premiums, contractor home office overhead and profit, payment and performance bond premiums, and contingency have been included to best predict overall project costs. Third-party expenses such as legal fees, land acquisition, and owner management costs have not been included.

In providing opinions of cost, financial analyses, economic feasibility projections, and schedules for potential projects, Carollo has no control over cost or price of labor and material; unknown or latent conditions of existing equipment or structures that may affect operation and maintenance costs; competitive bidding procedures and market conditions; time or quality of performance of third parties; quality, type, management, or direction of operating personnel; and other economic and operational factors that may materially affect the ultimate project cost or schedule. Actual project costs, financial aspects, economic feasibility, and schedules will vary from Carollo's opinions, analyses, projections, and estimates based on these factors.

7.6.1 Escalation Discussion

In early 2020, the construction community and vendor network that supports the water/wastewater industry experienced significant disruptions due to COVID-19 restrictions adding new and significant complexity to their operations, labor force management, and material supply chain. This has created a bidding environment that has been and remains very difficult to predict. Throughout the second half of 2020 and all of 2021/2022, there have been extraordinary cost increases in key materials commonly required by plant and pipeline projects and increased pressures on attracting and retaining quality craft labor.

Additionally, increasing fuel costs and massive congestion at the nation's ports and rail yards, combined with near record low warehouse and trucking capacity, have raised shipping prices to levels that far exceed historical norms. It is clear by reviewing bid results for projects procured during this period that prices have increased at a rate that far exceeds long-term escalation trends and the variability between bidders has increased making the pricing process more difficult to predict.

The construction outlook for 2023 retains many of the same concerns as the previous 2 years while also incorporating new ones. Even though the primary risks regarding the health and safety of the population due to the threat of COVID-19 and its variants appear to be diminishing and the corresponding restrictions on businesses are slowly being lifted, many of the challenges created by these past actions remain unresolved. Political events, economic policies, global trade disruptions, supply chain delays, fierce competition for labor, consumer inflation, rising fuel prices, and war have all created uncertainties that have impacted contractor pricing.

Consumers of construction cost estimate data should be advised that pricing accuracy is time sensitive and will degrade over relatively brief periods of time. Pricing updates should be made regularly to increase overall reliability.

Escalation for these estimates was calculated using a composite factor developed by Carollo to project cost increases based on typical results for treatment plants. Although 2023 maintains a challenging market, it appears that the escalation rates for most major commodities that support the industry are softening. It is also Carollo's expectation that this trend will continue over the next years and ultimately return to the normal range of values that have characterized the market for the last 70+ years. For this reason, a unique blended escalation rate was applied for each project phase based on its predicted schedule and mid-point to construction.

7.6.2 Cost Estimating Parameters and Adders

Cost estimates are comprised of both direct and indirect costs estimated for all planning, design, construction, construction management, and administration activities of the project. A summary of overall cost parameters and adders is included in Table 7.3.

Table 7.3 Cost Parameters and Adders

Capital Cost Parameter	Assumption
Construction Cost Factors	
Escalation(1)	Specific to each project timeline
General Conditions Labor, Expenses, and Equipment	15%
Builder's Risk and GL Insurance	1.25%
General Contractor Overhead and Profit	10%
Performance and Payment Bond	1.1%
Taxes	N/A – 0%
Design and Bidding Risk Contingency(2)	25% – Phases 1 and 2 30% – Phases 3, 4, and 5
Non-Construction Cost Factors	
Design and Permitting Costs	9%
Construction Management and Engineering Services During Construction	9%

Notes:
(1) Escalation to midpoint of each project phase was projected at the following rates:
Phase 1 – 18% to Q3 2025. Projecting an average rate of 7% per year.
Phase 2 – 30% to Q3 2027. Projecting an average rate of 6% per year.
Phase 3 – 39% to Q4 2029. Projecting an average rate of 5% per year.
Phase 4 – 53% to Q4 2031. Projecting an average rate of 5% per year.
Phase 5 – 80% to Q4 2037. Projecting an average rate of 4% per year.
(2) More project detail is available at this point for Phases 1 and 2 than Phases 3, 4, and 5.

Table 7.4 summarizes the construction and project costs for each phase, based on the evaluation developed for this purpose in March 2023. Key drivers in the costs are capacity, asset renewal, biosolids, reuse, and regulatory requirements.

Table 7.5 allocates the costs amongst these drivers. Figure 7.7 shows the projects and phasing on the site. Figure 7.8 summarizes the anticipated cash expenditures by year based on the projected schedule. Appendix 7A includes summaries of the project cost estimates for each phase. Appendix 7B includes a detailed full scope estimate for the compiled projects.

Table 7.4 Construction and Project Cost Estimates for Project Phases – March 2023

Project Phase	Construction Cost Estimate	Design and Permitting Cost Estimate	Construction Management and Engineering Services During Construction Cost Estimate	Project Cost Estimate
1	$31,278,000	$2,750,000	$2,815,000	$36,843,000
2	$149,464,000	$13,452,000	$13,452,000	$176,368,000
3	$100,556,000	$9,050,000	$9,050,000	$118,656,000
4	$53,826,000	$4,844,000	$4,844,000	$63,514,000
5	$108,569,000	$9,771,000	$9,771,000	$128,111,000

Notes:
(1) Cost estimates are based on project phasing, groupings, and components as of March 2023, as detailed in this chapter and in Appendix 7A. Adjustment to costs for Phase 1 made subsequent to detailed estimate and included replacement of secondary clarifier mechanisms and reuse pump VFDs.

Table 7.5 CIP Costs by Project Driver

Project Driver	Total Cost	Percent of Total Cost
Capacity	$87,167,500	17%
Asset Renewal	$104,055,350	20%
Biosolids	$92,750,850	18%
Reuse	$33,348,300	6%
Regulatory	$206,170,000	39%
Total	**$523,492,000**	

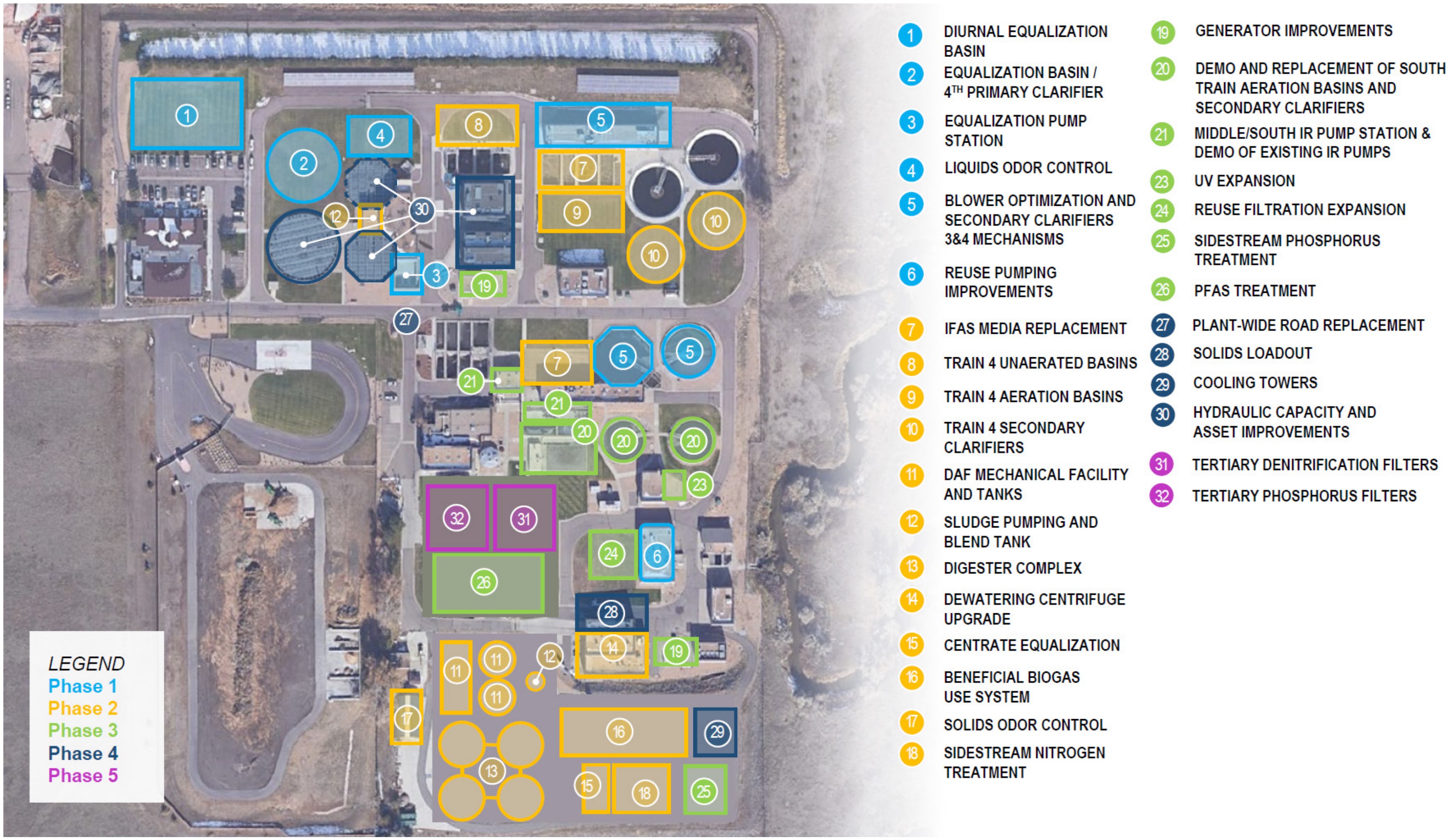

Figure 7.7 Proposed CIP Projects at BWRF

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Project	Phase	2023	2024	2025	2026	2027	2028	2029	2030	2031
1	Design	$ 137,500	$ 2,475,000	$ 137,500						
	Construction		$ 2,004,650	$ 22,160,450	$ 10,227,900					
2	Design	$ -	$ 1,345,200	$ 7,398,600	$ 4,708,200					
	Construction				$ 32,583,200	$ 57,020,600	$ 48,874,800	$ 24,437,400		
3	Design					$ 3,620,000	$ 4,977,500	$ 452,500		
	Construction							$ 21,921,200	$ 49,322,700	$ 38,362,100
4	Design						$ 242,200	$ 1,937,600	$ 2,422,000	$ 242,200
	Construction									$ 11,734,000
5	Design									
	Construction									
Annual Total		**$ 137,500**	**$ 5,824,850**	**$ 29,696,550**	**$ 47,519,300**	**$ 60,640,600**	**$ 54,094,500**	**$ 48,748,700**	**$ 51,744,700**	**$ 50,338,300**

Project	Phase	2032	2033	2034	2035	2036	2037	2038	2039	2040
1	Design									
	Construction									
2	Design									
	Construction									
3	Design									
	Construction									
4	Design									
	Construction	$ 26,401,500	$ 20,534,500							
5	Design			$ 97,710	$ 2,931,300	$ 5,862,600	$ 879,390			
	Construction						$ 41,419,000	$ 53,253,000	$ 23,668,000	
Annual Total		**$ 26,401,500**	**$ 20,534,500**	**$ 97,710**	**$ 2,931,300**	**$ 5,862,600**	**$ 42,298,390**	**$ 53,253,000**	**$ 23,668,000**	**$ -**

Figure 7.8 Projected Cash Flow Expenditures by Year

7.6.3 Cost Drivers

For each of the project components identified in these phases, the following drivers and assumptions affected costing of the work at the master planning level. These drivers will be reviewed in detail with Broomfield staff to determine appropriateness in the final CIP packaging.

7.6.3.1 Phase 1 Project

01 New Equalization Basin (Rectangular)

- Large above-ground concrete tank will be provided with architectural exterior veneer or form-liner finish.
- FRP/aluminum covers with external trusses similar to existing covers.
- Due to height, structure will be provided with external elevated walkways with handrails.
- Structure will be placed on drilled pier foundations.

02 New Equalization Basin (Circular)

- Basin will be buried approximately 10 feet below grade.
- FRP/aluminum covers with external trusses similar to existing covers.
- Structure will be placed on drilled pier foundations.
- Costs include future conversion to clarifier. Mechanism priced from recent quotes for similar equipment.

03 New Equalization Pump Station

- Complex retrofit of pumping area. Includes new floor, walls, operating deck, and concrete masonry unit (CMU) building.

04 New Liquid Stream Odor Control

- Odor control system concept price based on similar system for other projects.
- Pricing for odor control equipment recently quoted by vendor.
- Structure will be placed on drilled pier foundations.

05 Blower Optimization and Secondary Clarifiers 3 and 4 Mechanism Replacement

- Key scope items involve removal of two existing blowers and addition of two turbo blowers. Equipment pricing was based on recent pricing for other projects and actual quotes from existing blowers.
- Replacement of secondary clarifier mechanisms added after costing efforts at direction of Broomfield staff.

06 Reuse Pump Station Improvements

- Add fourth reuse pump and replace VFDs. Added after costing efforts at direction of Broomfield staff.

06A Site Preparation for Phase 2

- Involves demolition of surface of high-density polyethylene and concrete liners of existing basins. Structures are not deepened in this phase due to ongoing dewatering concerns.

7.6.3.2 Phase 2 Project

07 North and Middle Train IFAS Media Replacement

- Majority of costs are associated with the purchase of replacement media and equipment, which was quoted for the project.

08 Fourth Secondary Treatment Train Unaerated Basins

- Structure is set in a deep excavation requiring sheetpiling and dewatering.
- Structure will be placed on drilled pier foundations.
- Equipment includes four large paddle mixers and motor operated gates.

09 Fourth Secondary Treatment Train Aeration Basins

- Structures are set in a deep excavation requiring sheetpiling and dewatering.
- Structures will be placed on drilled pier foundations.
- Significant cost included for IFAS media, which was quoted for the project.

10 Fourth Secondary Treatment Train Secondary Clarifiers

- Structures are set in a deep excavation requiring sheetpiling and dewatering.
- Structures will be placed on drilled pier foundations.
- Significant costs for clarifier mechanisms priced from recent quotes for similar equipment.

11 DAF Tanks and Mechanical Building

- Structures will be placed on drilled pier foundations.
- Significant costs for process equipment priced from recent project data.

12 Blend Tank

- Above-ground concrete tank will be provided with an architectural exterior veneer or form-liner finish.
- Structure will be placed on drilled pier foundations.

13 Anaerobic Digester Complex

- Complex will be positioned in a large excavation requiring sheetpiling and dewatering.
- Structures will be placed on drilled pier foundations.
- The four proposed digester tanks have relatively large diameters and heights.
- Fixed digester covers will require relatively expensive material and installation costs.
- Equipment costs within support building for pumps, heat exchangers, boilers, and mixing equipment are significant and will require a high degree of complex interconnecting piping.
- Site-wide asphalt paving replacement.

14 Dewatering Centrifuge Upgrades

- Primary cost drivers are the purchase of centrifuges.
- Additional costs are included for removal and replacement of the elevated access platform.

15 Centrate Equalization Tank

- Above-ground concrete tank will be provided with an architectural exterior veneer or form-liner finish.
- Structure will be placed on drilled pier foundations.

16 Beneficial Biogas Use System

- Majority of costs related to process equipment purchase.

17 Solids Odor Control

- Odor control system concept price based on similar system for other projects.
- Pricing for odor control equipment recently quoted by vendor.
- Structure will be placed on drilled pier foundations.

18 Sidestream Nitrogen Treatment

- Primary cost driver is the purchase of media, diffusers, screens, mixers, etc.
- Secondary costs are related to an above-ground concrete tank placed on drilled pier foundations.

7.6.3.3 Phase 3 Project

19 Generator Improvements

- Facility costs include a new CMU structure positioned on drilled piers.
- An external cast-in-place concrete diesel tank with secondary containment is included.
- Costs are included for two new 750-kW generators with automatic transfer switches.

20 South Train IFAS Basins and Secondary Clarifiers

- Scope includes demolition of existing IFAS basins and secondary clarifiers.
- Structures are set in a large, common deep excavation requiring sheetpiling and dewatering.
- Structures will be placed on drilled pier foundations.
- Significant cost included for IFAS media and equipment, which were quoted for the project.
- Costs include clarifier mechanisms priced from recent quotes for similar equipment.

21 IR Pump Station

- Excavation costs include sheetpiling and dewatering.
- Pump station will include a concrete wet well and CMU building.
- Facility includes four centrifugal pumps.

22 Demo Odor Control Facility

- Demolition costs includes removal and disposal of structure.

23 UV Expansion

- Facility costs include demolition of east wall of existing UV structure and construction of a new identical channel adjacent to existing.
- UV Facility will be expanded to include additional channel.
- UV process equipment purchase represents a significant cost for the structure.

24 Reuse Filtration Expansion

- Excavation costs include sheetpiling and dewatering.
- Pump station will include a concrete wet well and CMU building.
- Facility includes a filtration equipment package quoted for a similar past project and adjusted in scale for the project.

25 Sidestream Phosphorus Treatment

- Majority of costs are associated with process equipment quoted for the project.
- Secondary costs include sitework, concrete, and supporting utilities.

26 PFAS Treatment System

- Majority of costs are associated with purchase and installation of PFAS equipment package.
- Other costs are related to demolition of two sludge holding tanks, three digesters, and a waste pump station.

7.6.3.4 Phase 4 Project

27 Plant-Wide Road Replacement

- Majority of costs are related to plant-wide road removal and replacement with concrete roads, including segment from plant entrance to Lowell.

28 Solids Loadout

- Process equipment purchase for hoppers and associated truck loading equipment is primary cost component.
- Significant costs included for multi-story building and truck loading area.

29 Cooling Towers

- Majority of costs are associated with purchase and installation of cooling towers equipment package.

30 Hydraulic Capacity and Asset Improvements

- This project was priced as an allowance due to limited available information.

7.6.3.5 Phase 5 Project

30 Tertiary Denitrification Filter

- Costs are factored based on a past project.

31 Tertiary Phosphorus Filter

- Costs are factored based on a past project.

7.6.4 Cost Control Opportunities

The costs presented in this chapter represent the initial packaging of projects at the BWRF over the next 20 years and were developed to reflect the timely execution of significant projects at the WRF. Cost control opportunities include changing project scopes, delaying project components, and refining project design considerations such that contingencies can be reduced.

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Appendix 2A

PROCESS DISCIPLINE ASSESSMENT

Appendix 2B

MECHANICAL DISCIPLINE ASSESSMENT

Appendix 2C

STRUCTURAL DISCIPLINE ASSESSMENT

Appendix 2D

ELECTRICAL DISCIPLINE ASSESSMENT

Appendix 2E

I&C DISCIPLINE ASSESSMENT

Appendix 3A

UNIT PROCESS CAPACITIES

Appendix 3B

CAPACITY ANALYSIS PROCESS MODELING SUMMARY

Appendix 3C

BIOWIN PROCESS MODEL CALIBRATION SUMMARY

Appendix 3D

MEMBRANE BIOREACTOR MODELING RESULTS

Appendix 3E

IFAS MODELING RESULTS

Appendix 3F

VEOLIA IFAS SYSTEM QUOTE

Appendix 3G

VEOLIA ANITA® MOX SYSTEM QUOTE

Appendix 3H

MANUFACTURERS' TECHNOLOGY PROPOSALS

Appendix 7A

SUMMARY PROJECT COST ESTIMATES FOR EACH PROJECT PHASE

Appendix 7B

DETAILED COST ESTIMATE FOR ALL PROJECT COMPONENTS