Chapter 5.
Water Quality Issues and Treatment Options

This chapter describes the general quality of the water near the diversion area and near the likely delivery areas, evaluates alternative levels of treatment and processes required for a plant near the diversion area to achieve various water quality goals, and presents conceptual-level plant layouts. Potential construction and operating costs for treatment are presented in the next chapter with similar information for the other physical facilities required for the CRRP.

Identification of Potential Water Treatment Levels

The following levels of treatment for the project water were considered during the study:

- No Treatment – This “option” is discussed herein only to document its infeasibility; issues are probably obvious to most readers, but other impacts may not be.
- Treatment Level One (Drinking Water Quality) – Treatment to finished drinking water quality of typical Front Range municipal systems (Safe Drinking Water Act, USEPA primary and secondary standards as well as typical front range aesthetics issues such as hardness)
- Treatment Level Two (Receiving Water Quality) – Treatment to match average receiving water quality

Each level of treatment would result in a specific set of water quality parameters that would characterize the project water discharged into the delivery area. The water quality parameters are compared along with the diversion area water quality parameters in the following sections.

Water Quality Data Sources

As shown on Figure 5-1, water quality along the Colorado River degrades in the downstream direction. Water quality data from the potential diversion area and for the potential receiving waters were obtained from the USGS website. Locations included the following:

- Colorado River Near Colorado-Utah State Line - USGS 09163500
- Colorado River at left bank near Panorama Bottomlands - USGS 390626108393501
- Colorado River Near Fruita, Colorado - USGS 09153000
- Colorado River near Cameo, Colorado – USGS 09095500
- Colorado River near DeBeque, Colorado – USGS 09093700

- Colorado River below Glenwood Springs, Colorado – USGS 09085100
- Colorado River near Dotsero, Colorado – USGS 09070500
- Colorado River at Hot Sulphur Springs, Colorado – USGS 09034500
- Middle Fork South Platte River near Hartsel, Colorado - USGS 06694100
- South Fork South Platte River above Fairplay, Colorado - USGS 06694400
- Clear Creek near Lawson, Colorado - USGS 06716500
- Hoop Creek at Mouth near Berthoud Falls, Colorado - USGS 394634105465800
- Blue River near Dillon, Colorado - USGS 09046600
- Snake River near Montezuma, Colorado - USGS 09047500
- Tenmile Creek at Frisco, Colorado - USGS 09050000
- Blue River below Green Mountain Reservoir, Colorado – USGS 09057500
- Blue River below Dillon, Colorado - USGS 09050700
- Government Highline Canal near Mack Colorado - USGS 09095530
- East Fork Arkansas River near Leadville, Colorado - USGS 07079500
- Columbine Ditch near Fremont Pass, Colorado - USGS 09061500

USGS water quality data was sorted and compiled using the filtered inorganic raw water quality. The 80th percentile is utilized for the diversion and delivery area waters as a standard practice to provide representative values on which to base treatment decisions. Using the maximum values or average values would put too much emphasis on infrequent data spikes (outliers) that are not common and could be accommodated through treatment plant operations versus configuring the treatment processes to continually handle these conditions.

Comparison of Water Quality and Potential Treatment Levels

To identify the processes required to meet the levels of treatment considered for the CRRRS, a comparison is needed between the raw water quality (at the diversion area) and the desired treated water quality for each parameter of concern. The first step was to identify the most important constituents regarding treatment as it would be impractical to evaluate every possible constituent in the water. Three categories of constituents are identified for comparison, which are the constituents that define the **primary** drinking water standards (Table 5-1), the constituents that define the **secondary** drinking water standards (Table 5-2) and the constituents that are typical of **Front Range Aesthetic Treatment Goals** (Table 5-3). These constituents make up the left column of the three tables. Tables 5-1, 5-2 and 5-3 provide a side-by-side comparison of the diversion area water quality, with the Level One Treatment (drinking water quality) parameters and the Level Two Treatment (receiving water quality) parameters.

In most cases, the higher a parameter's value in the tables, the lower the water quality. In cases where the value in the diversion area water is higher than the value for the treatment level, treatment of that parameter would be required. These occurrences are shaded in the tables. As the difference between the diversion area value and the treatment level value increases, the degree of required treatment increases.

To allow comparison of the two treatment levels in cases where the diversion area value is higher than both treatment levels, the lowest value for the treatment levels is highlighted in bold indicating a higher degree of treatment is needed (see turbidity, for example). In all cases except turbidity, treatment level two (receiving water quality) values are lower indicating this would be a higher level of treatment. This makes sense because the delivery waterbodies typically are more pristine high elevation waters (with the exception of microbials such as Cryptosporidium or Giardia) that are generally higher quality than drinking water standards.

Table 5-1: Water Quality Data Compared to Primary Drinking Water Standards

Parameter	Diversion Area Water Quality	Characteristics of Water Treatment Levels	
		Level One – Treatment to Primary Drinking Water Standard	Level Two - Treatment to Delivery Area Water Quality
Inorganics			
Antimony (mg/L)	0.001	0.006	0.001
Arsenic (mg/L)	0.002	0.010	0.001
Asbestos (fibers/L > 10 μm long)	---	7 MFL	---
Barium (mg/L)	0.11	2	0.04
Beryllium (mg/L)	0.001	0.004	0.001
Cadmium (mg/L)	0.002	0.005	0.001
Chromium (total) (mg/L)	0.1	0.1	0.001
Cyanide (as free cyanide) (mg/L)	---	0.2	---
Fluoride (mg/L)	0.4	4.0	0.4
Lead (mg/L)	0.011	0.015	0.002
Mercury (mg/L)	---	0.002	---
Nitrate (as N) (mg/L)	1.3	10	0.1
Nitrite (as N) (mg/L)	0.05	1	0.01
Selenium (mg/L)	0.01	0.05	0.001
Sodium (mg/L)	110	160	15
Thallium (mg/L)	---	0.002	---
Radionuclides			
Combined Radium 226/228 (pCi/L)	---	5	---
Beta particle and photon emitters (mrems/yr)	---	4	---
Alpha emitters (pCi/L)	---	15	---
Uranium (ug/L)	1.1	30	1.5
Microbials			
Cryptosporidium	---	TT	---
Giardia lamblia	---	TT	---
Heterotrophic plate count (HPC)	---	TT	---
Legionella	---	TT	---
Total coliforms	---	5%	---
Turbidity (NTU)	181	**0.3**	1.7
Viruses	---	TT*	---

"---" indicates data not available or not applicable. TT – depends on the use of specific treatment techniques

Table 5-2: Water Quality Data Compared to Secondary Drinking Water Standards

Parameter	Diversion Area Water Quality	Characteristics of Water Treatment Levels: Level One – Treatment to Secondary Drinking Water Standard	Characteristics of Water Treatment Levels: Level Two - Treatment to Delivery Area Water Quality
Aluminum (mg/L)	0.04	0.05 to 0.2	---
Chloride (mg/L)	96	250	18
Color (color units)	---	15	---
Copper (mg/L)	0.015	1.0	0.0028
Corrosivity - LSI	+1.3	+0.1	**-0.3**
Fluoride (mg/L)	0.4	2.0	0.4
Foaming Agents (mg/L)	---	0.5	---
Iron (mg/L)	0.03	0.3	0.03
Manganese (mg/L)	0.02	0.05	0.07
Odor	---	3	---
PH	8.4	6.5-8.5	7.8
Silver (mg/L)	0.001	0.1	0.001
Sulfate (mg/L)	350	250	**49**
Total Dissolved Solids (mg/L)	790	500	**148**
Zinc (mg/L)	0.05	**5**	0.12

"---" indicates data not available or not applicable.

Table 5-3: Water Quality Data Compared to Front Range Aesthetic Treatment Goals

Parameter	Diversion Area Water Quality	Characteristics of Water Treatment Levels: Level One – Treatment to Front Range Aesthetic Goals	Characteristics of Water Treatment Levels: Level Two - Treatment to Delivery Area Water Quality
Total Hardness (mg/L as $CaCO_3$)	460	125	**120**
Calcium (mg/L as $CaCO_3$)	275	75	**73**
Magnesium (mg/L as $CaCO_3$)	185	50	**47**
Alkalinity (mg/L as $CaCO_3$)	154	100	**49**
TOC (mg/L)	13	2.0	**1.9**
DOC (mg/L)	3.8	2.0	**1.6**

No Treatment

No treatment of the diversion area water would increase the concentrations for many of the parameters listed in Tables 5-1 through 5-3 for the receiving waters in the delivery area. The magnitude of the increased concentrations would depend upon the dilution effects between the two waters.

The higher turbidities would affect the pristine look of the receiving water and there could be impacts to flora and fauna. The no treatment option would also result in solids deposition and scaling of the pipeline, which may be problematic. In addition, the no treatment option would impact municipal water providers that utilize these waters.

Without treatment incorporated into the CRRP, existing municipal treatment processes would need to be enhanced to meet SDWA standards and to meet customer expectations. Municipal systems along the Front Range typically employ coagulation for turbidity removal. However, they are not typically equipped to reduce hardness, sulfates, TDS, or SOCs. Coagulation processes can be updated to reduce TOC via enhanced coagulation. There are two potential approaches: 1) meet SDWA standards and 2) to meet customer expectations.

Impacts on non-potable water systems, (for example, increases in TDS and salt loading) would also be considered a negative impact by most irrigation users.

For the purposes of this reconnaissance study, it is assumed that the CRRP would have to incur the cost of treatment so that there would be maximum flexibility in using the water in all three river basins (Colorado, Arkansas, and South Platte) as directed by the state. Therefore, the “no treatment” option was not considered further in this study.

Treatment Level One - Matching Finished Water Quality of Typical Front Range Municipal Systems

Comparison of the diversion area and finished water quality of typical Front Range municipal systems indicates that treatment would be required for Turbidity, Sulfate, TDS, Hardness (Calcium and Magnesium), Alkalinity, and TOC (including DOC).

Treatment Level Two – Matching Delivery Area Water Quality

Comparison of the diversion area and delivery area water quality indicates that treatment would be required for Arsenic, Barium, Cadmium, Chromium, Copper, Lead, Nitrate, Nitrite, Selenium, Turbidity, Chloride, Sodium, Sulfate, pH, TDS, Hardness (Calcium and Magnesium), Alkalinity, and TOC (including DOC).

Alternative Treatment Processes

Alternative treatment processes to remove or reduce the parameters of concern are presented below for the two treatment levels. For both levels of treatment, the constituents representing the key issues for treatment process selection are shown in Table 5-4 with the best available treatment techniques for these water quality constituents.

Table 5-4: Treatment Techniques for Water Quality Parameter of Concern

Water Quality Parameter of Concern	Treatment Technique	Category
Suspended Solids/ Turbidity	• Coagulation • Microfiltration • Ultrafiltration	Pretreatment
Hardness	• Lime Softening • Nanofiltration • Ion-Exchange (zeolite)	Advanced Treatment
TDS/ Sulfate	• Nanofiltration • Reverse Osmosis • Electrodialysis Reversal	Advanced Treatment
TOC/ SOC	• Nanofiltration • Reverse Osmosis • Granular Activated Carbon	Advanced Treatment
Microbials	• Chlorination/ Dechlorination • UV	Post Treatment

Treatment was further separated into categories based on level of treatment. The following briefly describes each category.

- **Pretreatment –** Involves processes needed to remove suspended solids/ turbidity. Pretreatment also protects the integrity of advanced treatment.
- **Advanced Treatment –** Involves processes needed to remove hardness, TDS, sulfates, TOC and SOC. Selection of specific processes is dependent upon selection of the levels of treatment needed.
- **Post Treatment -** Involves processes needed to provide receiving water integrity (inactivate microbials without residual disinfectant and use of chemical oxidants which produce DBPs) and pipe integrity protection (corrosion/scale control). The rationale for including disinfection is the prevention of a point source for microbial contamination of alpine water bodies. It is possible that disinfection could be eliminated and this should be evaluated under future studies.

The treatment techniques were reviewed and the following are selected for evaluation:

- Coagulation, Sedimentation, Filtration (C/S/F)
- Ultrafiltration (UF)
- Lime Softening, Filtration (LS/F)
- Nanofiltration (NF)
- UV Disinfection (UV)

Table 5-5 presents the individual treatment technique performance relative to removal of the parameters of concern. To use this table, combinations of treatment techniques were selected that result in removal of the parameters of concern.

Table 5-5: Treatment Performance Conceptual Evaluation

Parameters	Treatment Alternative				
	Pre-Treatment		**Advanced Treatment**		**Post-Treatment**
Raw Water Quality	**C/S/F**	**UF**	**LS/F**	**NF**	**UV**
INORGANICS:					
-TDS	N	N	P	E	N
-Iron (Dissolved)	N	N	N	E	N
-Iron (Total)	P	P	P	P	N
-Hardness	N	N	E	E	N
-Sulfate	N	N	P	E	N
ORGANICS:					
-Color	P	N/P[1]	N	E	N
-TOC	P	N/P[1]	P	E	N
-SOCs	N	N	N	E	N
MICROBIALS:					
-Turbidity	E	E	P	P	N
-*Cryptosporidium/Giardia*	P	E	P	P	E
-Bacteria	P	E	P	P	E
-Viruses	P	E	P	P	P

Legend		
N = Not generally effective. P = Partially effective E = Effective	C/S/F – Coagulation/Sedimentation/Filtration UF – Ultrafiltration LS/F – Lime Softening/Filtration	NF – Nanofiltration UV – Ultraviolet Disinfection

1. Ultrafiltration is partially effective at removal of color and TOC when a coagulant is used upstream.

Table 5-6 presents the advantages and disadvantages of the individual treatment processes.

Table 5-6: Conceptual Level Advantages and Disadvantages of Treatment Alternatives

Alternative	Advantages	Disadvantages
Coagulation	• DBP precursor removal (limited) • Particle destabilization • Relatively small footprint with ACTIFLOW® process	• Additional waste residual stream produced • High chemical use • Jar test recommended • No SOCs
Ultrafiltration	• Effective particle removal, including turbidity and pathogens • High removal of *Cryptosporidium* and *Giardia* • Small footprint • Easy Automation, less labor-intensive	• Does not reduce TDS • Cannot remove DBP precursors • Additional power costs • Has residuals to be disposed • Pilot testing required
Lime Softening	• Taste and odor control (limited) • Biological growth control • Conditions and softens water • Removes inorganics and radionuclides • Removes hardness, scale	• Not effective at sulfide removal • Produces sludge waste stream • Requires sludge handling facility • Reduces finished water alkalinity • Jar test recommended • More labor-intensive than membrane systems
Nanofiltration	• Reduces chlorine demand • Conditions and softens water • Removes bacteria and viruses • Reduces TDS and chlorides • Reduces inorganics, radionuclides • Mainly enclosed operations • Removes DBP precursors	• Concentrate disposal required • Post-treatment required • Pilot testing required • Membranes subject to fouling • Reduced finished water alkalinity • No sulfide removal
UV Disinfection	• Reduces chlorine requirements for disinfection (CT), lower chlorine dosage leads to lower DBP formation • Effective pathogen inactivation (including *Cryptosporidium* and *Giardia)* • No known by-products • Does not chemically alter the water	• Intensive operations and maintenance • Some power costs increase
Cl_2/Dechlor	• Limited pathogen inactivation (bacteria and microbes)	• Not effective for *Cryptosporidium* and *Giardia*

Using Tables 5-5 and Table 5-6, it was determined that a combination of processes would be needed to remove the parameters of concern. The following four (4) water treatment alternatives were developed for meeting the treatment levels considered and are described in detail in the next section:

- **Alternative 1**: Ultrafiltration/Nanofiltration/UV
- **Alternative 2**: Coagulation/Sedimentation/Enhanced Lime Softening/Filtration/UV
- **Alternative 3**: Coagulation/Sedimentation/Filtration/Nanofiltration/UV
- **Alternative 4**: Enhanced Lime Softening/Filtration/UV

Alternatives 1 and 3 are geared toward meeting treatment level two (receiving water quality) (see p. 5-1). Alternatives 2 and 4 are geared towards meeting treatment level one (drinking water quality). The processes included in Alternatives 2 and 4 were not intended to meet the treatment level two requirements, and will not, as can be seen with the use of Table 5-5.

Detailed Descriptions of the Treatment Alternatives

Ultrafiltration/Nanofiltration/UV (Alternative 1)

Alternative 1 includes ultrafiltration (UF), nanofiltration (NF), and UV disinfection. The ultrafiltration process provides particle removal (turbidity), including pathogen removal. The nanofiltration process removes hardness, TDS and sulfates. An approximate 25% bypass around the nanofiltration process blends the UF filtrate with NF softened permeate to meet the hardness goal of 120 mg/L as $CaCO_3$. The UV disinfection provides pathogen inactivation without residual prior to discharge to the delivery points. Figure 5-2 presents the process flow diagram for Alternative 1.

Pretreatment

Automatic self-cleaning backwashable strainers are located upstream of the UF units to remove larger particles to extend the run times of the UF units. The UF filtrate flows to an equalization tank that supplies the nanofiltration process, while the UF waste flow is returned to the river. Coagulation upstream of the UF units is optional to enhance turbidity removal and to remove a portion of the dissolved organics (TOC). However, adding coagulant ahead of UF may limit or disqualify return of UF waste back to the river, which is discussed later under the residuals handling section of this chapter.

Advanced Treatment

Following ultrafiltration, a portion of the flow is treated by the NF process while a portion of the flow is bypassed and blended with the NF permeate to meet water treatment goals. An approximate 25% UF filtrate bypass around the nanofiltration process was calculated to meet the level two (receiving water quality) treatment requirements.

The NF concentrate is further concentrated with reverse osmosis (RO) to minimize the concentrate stream. The RO permeate is blended with the NF permeate and the bypass UF Filtrate stream while the RO concentrate is discharged to evaporation ponds, which is discussed under the residuals handling section of this chapter.

Post Treatment

Water from the advanced treatment processes flows to storage tanks. UV disinfection can be provided upstream or down stream of the ground storage tanks. UV was recommended to prevent a point source microbial contamination of the receiving waters, which are the primary water sources for Front Range municipal drinking water systems. pH adjustment was also included to meet the treatment goals and for pipeline protection.

Coagulation/Sedimentation/Lime Softening/Filtration/UV (Alternative 2)

Alternative 2 includes coagulation/sedimentation, lime softening, rapid sand filtration, and UV disinfection. The coagulation/sedimentation process provides particle removal (turbidity), including pathogen removal and reduces organics. The lime softening process reduces hardness and TDS. Note that sulfate removal is not effective using lime softening. The UV disinfection provides pathogen inactivation without residual prior to discharge to the delivery area. Figure 5-3 presents the process flow diagram for Alternative 2.

Pretreatment

Coagulation/sedimentation is achieved using a ballasted floc system in order to minimize treatment plant footprint. The settled sludge from the ballasted floc system is recycled to the hydroclone where the microsand is separated from the sludge and mixed back into the feed water. The separated sludge flows to the sludge thickener.

Advanced Treatment

The clarified water from the ballasted floc system flows to the lime softening solids contact clarifier where lime and soda ash are added. The settled sludge from the lime softening solids contact clarifier flows to the sludge thickener.

The overflow from the lime softening solids contact clarifier flows into a two-stage recarbonation basin for pH adjustment and stabilization. Blowdown from the first stage recarbonation basin flows to the sludge thickener.

After stabilization, water flows to the rapid sand filters to remove the remaining solids from the flow stream. Backwash water from the sand filters flows to the backwash recovery basin for settling, the settled backwash water is returned to the head of the plant, while the blowdown flows to the sludge thickener. The sludge thickener supernatant flows to the backwash water recovery basin, and the thickened sludge is then dewatered. The dewatered sludge would require disposal, which is discussed under the residuals handling section of this chapter. Water from the dewatering process is returned to the sludge thickener.

Post Treatment

Post treatment processes are similar to the processes described under Alternative 1.

Coagulation/Sedimentation/Filtration/Nanofiltration/UV (Alternative 3)

Alternative 3 is similar to Alternative 1 with the modifications made to the pretreatment processes. Essentially the ultrafiltration process is replaced with a conventional filtration process. This eliminates the ultrafiltration waste stream, but adds an additional sludge handling component and increases the treatment plant footprint size.

Alternative 3 includes coagulation/sedimentation/filtration, nanofiltration (NF), and UV disinfection. The coagulation/sedimentation process provides particle removal (turbidity), including pathogen removal and reduces organics. The nanofiltration process removes hardness, TDS and sulfates. An approximate 25% bypass around the nanofiltration process blends the filtrate with NF softened permeate to meet the hardness goal. The UV disinfection provides pathogen inactivation without residual prior to discharge to the delivery points. Figure 5-4 presents for the process flow diagram for Alternative 3.

Pretreatment

Coagulation/sedimentation is achieved using the ballasted floc system. The settled sludge from the ballasted floc system is recycled to the hydroclone where the microsand is separated from the sludge and mixed back into the feed water. The separated sludge flows to the sludge thickener.

The clarified water from the ballasted floc system flows to the gravity rapid sand filters to remove the remaining solids from the flow stream.

Backwash water from the sand filters flows to the backwash recovery basin for settling. The settled backwash water is returned to the head of the plant, while the blowdown flows to the sludge thickener. The sludge thickener supernatant flows to the backwash water recovery, and the thickened sludge is then dewatered. The dewatered sludge would require disposal, which is discussed under the residuals handling section of this chapter. Water from the dewatering process is returned to the sludge thickener.

Advanced Treatment

Following conventional filtration, a portion of the flow is treated by the NF process while a portion of the flow is bypassed and blended with the NF permeate to meet water quality goals. An approximate 25% prefiltered bypass around the nanofiltration process was calculated to meet the level two treatment requirements.

The NF concentrate is further concentrated with reverse osmosis (RO) to minimize the concentrate stream. The RO permeate is blended with the NF permeate and the bypass stream while the RO concentrate is discharged to evaporation ponds, which is discussed under the residuals handling section of this chapter.

Post Treatment

Post treatment processes are similar to the processes described under Alternative 1.

Lime Softening/Filtration/UV (Alternative 4)

Alternative 4 is essentially Alternative 2 without the pretreatment processes. This alternative would generally be less expensive in all areas, but is not as effective in meeting the treatment requirements.

Alternative 4 includes lime softening, rapid sand filtration, and UV disinfection. The lime softening process reduces hardness and TDS and the filter reduces turbidity. Note that sulfate removal is not effective using lime softening. The UV disinfection provides pathogen inactivation without residual prior to discharge to the delivery points. Figure 5-5 presents the process flow diagram for Alternative 4.

Advanced Treatment

The lime softening is achieved in a solids contact clarifier where lime and soda ash are added. The settled sludge from the lime softening solids contact clarifier flows to the sludge thickener.

The overflow from the lime softening solids contact clarifier flows into two-stage recarbonation basin for pH adjustment and stabilization. Blowdown from the first stage recarbonation basin flows to the sludge thickener.

After stabilization, water flows to the rapid sand filters to remove the remaining solids from the flow stream. Backwash water from the sand filters flows to the backwash recovery basin for settling, the settled backwash water is returned to the head of the plant, while the blowdown flows to the sludge thickener. The sludge thickener supernatant flows to the backwash water recovery basin, and the thickened sludge is then dewatered. The dewatered sludge would require disposal, which is discussed under the residuals handling section of this chapter. Water from the dewatering process is returned to the sludge thickener.

Post Treatment

Post treatment processes are similar to the processes described under Alternative 1.

Residuals Handling Issues

Residual Production – Quantity and Characterization

Each of the treatment alternatives produces some form of residual byproducts that must be processed and disposed of in some manner. The residual streams from each process are shown on Figures 5-2 through 5-5. The alternatives produce a combination of the following residuals streams:

- UF backwash/reject
- Filter backwash
- NF/RO concentrate
- Coagulation sludge
- Lime sludge

The above residuals streams can be divided into two categories. The first are concentrate solutions produced from membrane processes that consist primarily of brackish water with high concentrations of suspended and dissolved solids. The dissolved solids are not easily removed from the water. UF backwash and NF/RO concentrate are produced in Alternatives 1 and 3. It should be noted that the UF Backwash Reject primarily consists of suspended solids with fewer dissolved solids than does the NF/RO concentrate.

The second category of residuals are sludges that are high in suspended solids that can be relatively easily isolated from the water, through the dewatering process and then disposed of in a solid form. Filter backwash, coagulation sludge and lime sludge fit into this category and some or all of these sludges are produced in Alternatives 2, 3 and 4.

Table 5-7 presents the predicted amount of residuals produced from each alternative at each of the flow rates. Since all of these residual streams include water as a major constituent, the disposal of this residual results in less water being treated than is diverted from the river. For example, Alternative 1 results in approximately 10 percent of the diverted flow that cannot be easily recovered. As will be discussed under the residuals disposal section, alternatives 2, 3 and 4 allow some of this water to be returned to the process.

In order to put these numbers in perspective, the following analogies are helpful. For the middle project delivery capacity (460 – MGD Treatment Capacity), the NF/RO process produces a residuals stream of 44 million gallons per day. This amount of water would fill a 135 acre-foot reservoir every day.

The dewatered sludge, resembling a damp soil, produced with Alternative 2 for the middle project delivery capacity is 192,000 cubic feet per day. If the dewatered sludge were placed with an even depth on a football field, the depth produced during one day would be a little over four feet.

Table 5-7: Predicted Quantity of Residuals

Treatment Capacity Corresponding to the Three Project Delivery Capacities	Brine Production		Sludge Production					
	NF/RO Concentrate (MGD)	UF Reject (MGD)	Lime Sludge[1] (tons/day)	Ferric Sludge[2] (tons/day)	Total Sludge (tons/day)	Lime Sludge[3] (ft^3/day)	Ferric Sludge[3] (ft^3/day)	Total Sludge[3] (ft^3/day)
Alternative 1								
690-MGD	66	40	---	---	---	---	---	---
460-MGD	44	23	---	---	---	---	---	---
230-MGD	22	13	---	---	---	---	---	---
Alternative 2								
690-MGD	---	---	2,300	900	**3,200**	209,000	80,000	**289,000**
460-MGD	---	---	1,500	600	**2,100**	139,000	53,000	**192,000**
230-MGD	---	---	800	300	**1,100**	70,000	27,000	**97,000**
Alternative 3								
690-MGD	66	---	---	900	**900**	---	78,000	**78,000**
460-MGD	44	---	---	600	**600**	---	52,000	**52,000**
230-MGD	22	---	---	300	**300**	---	26,000	**26,000**
Alternative 4								
690-MGD	---	---	3,000	---	**3,000**	275,000	---	**275,000**
460-MGD	---	---	2,000	---	**2,000**	183,000	---	**183,000**
230-MGD	---	---	1,000	---	**1,000**	92,000	---	**92,000**
Notes								
1. Lime Sludge (lb/MG) = 8.34 x (2.0Ca + 2.6 Mg + SS) - Ca = calcium removed in mg/L as $CaCO_3$, Mg = magnesium removed in $CaCO_3$, SS = suspended solids (mg/L) -From "Integrated Design and Operation of Water Treatment Facilities, 2nd Edition", Kawamura, 2000								
2. Ferric Sludge (lb/MG) = (Ferric sulfate dosage (mg/L) x (0.54 x 8.34)) + (raw water turbidity (ntu) x 1.3 x 8.34), From Integrated Design and Operation of Water Treatment Facilities, 2nd Edition", Kawamura, 2000								
3. Based on a 30% solids concentration.								

Residuals Disposal

Alternative 1 produces a suspended solids laden UF reject and a concentrated dissolved solids NF/RO concentrate. It has been assumed the UF reject can be discharged downstream of the Diversion Point intake structure. This is a typical practice with UF reject as long as chemical coagulants have not been added. The practice basically returns the solids back to the river. However, due to the large size of this facility this concept would need to be evaluated further and may require a discharge permit. If unable to return the solids to the river, the UF stream would be sent to holding ponds for dewatering.

Alternative 3 does not produce a UF reject stream, but does produce a concentrated dissolved solids NF/RO concentrate. For the purposes of this study it has been assumed that the NF/ RO concentrate will be sent to evaporation ponds. These ponds will be very large. Based on an evaporation rate of 3.5 feet per year, the surface area required for the middle project delivery capacity would be approximately 14,000 acres or approximately 22 square miles. Later chapters discuss the environmental factors associated with evaporation ponds this large. Further study would be required to identify ways to reduce or utilize the concentrate stream. These might include additional pilot studies to identify potentially higher recovery rates or additional treatment of the concentrate stream itself to reduce the quantity.

Additional methods and combinations of methods for disposal or utilization of the stream should be studied. Most large plants similar to this have been built near coastal areas where ocean discharge is feasible. Most inland plants are small and use some form of surface water discharge tied with another stream (such as wastewater discharges) for dilution. New large inland plants are being evaluated, but not enough have been built yet for technology to efficiently address the concentrate issue. Considerable research is ongoing on this subject and new technologies may reduce the magnitude of this issue. Deep well injection was considered, but not explored in great detail. Inducement of seismic activity and clogging of formations has been observed for deep well injection for much smaller quantities than this. Enhanced evaporation, vegetative uptake, and zero liquid discharge (thermal processes) should also be evaluated. Other considerations could include utilization of the water in the energy exploration industry. For example, it may be possible to use the water for oil or gas displacement. The water quality in these areas is typically poor, and therefore the effect on the environment may not be too significant. Other options may include use of the water for a coal slurry pipeline to a coastal area. Concentrate streams from similar plants in coastal areas have disposed the concentrate stream into the ocean typically in conjunction with other streams such as power plant cooling water that reduce the impacts. With the evaporation or zero-discharge approaches, a final solid product consisting of salts would be produced requiring disposal.

Alternatives 2, 3, and 4 include sludge producing processes that would need to be thickened in tanks and then placed on dewatering beds requiring approximately 250 acres for the 500,000 af/yr delivery capacity. Wind, sun and the freeze-thaw process help separate the water from the solids, part of which is evaporated and part of which is returned to the treatment process. When enough water has been removed from the sludge so that is can be handled, it is removed from the dewatering beds and stored for ultimate disposal. Ultimate disposal would likely be land application and further study would be required to determine the ability to dispose of this sludge and possibly the marketability of the product.

Conceptual Treatment Plant Layouts

Conceptual layouts were prepared for each alternative at the 690-MGD flow rate to show the largest area required and are shown in Figures 5-6 through 5-9. For the purposes of this study the land required is scalable to the project delivery capacity. The layouts include Pretreatment, Advanced Treatment, Post-Treatment and Residuals Handling facilities. These layouts do not show details such as storm water retention, roadways or residuals storage. Residuals storage land area for the evaporation ponds is described in the previous section. The amount of land for dewatering the sludge has been estimated to be equal to the land required for the main processes.

Table 5-8 presents the characteristics and land requirements of each alternative. When looking at the treatment process only, Alternative 1 had the smallest land requirement, while Alternative 2 and Alternative 4 had the largest land requirement. Membrane plants tend to require less land for the process equipment than conventional treatment. However, total land required when residuals storage is included is much higher for the membrane plants.

Table 5-8: Layout Characteristics for a 690-MGD Treatment Plant

	Treatment Alternative			
	#1	#2	#3	#4
PARAMETER	**UF/NF/UV**	**C/S/LS/F/UV**	**C/S/F/NF/UV**	**LS/F/UV**
TREATMENT PLANT				
Pre-treatment	UF - 95% Recovery • 10 Buildings • 76-MGD per Building	C/S • 30 Trains* • 26-MGD per Train*	C/S/F • 28 Trains* • 27-MGD per Train*	---
Advanced Treatment	NF – 85% Recovery • 10 Buildings • 69-MGD per Building	LS/F • 30 Trains* • 23-MGD per Train*	NF – 85% Recovery • 10 Buildings • 69-MGD per Building	LS/F • 15 Trains* • 46-MGD per Train*
Post Treatment	UV • 4 UV Buildings • 173-MGD per Building GST • 230-MGD per Train*	UV • 4 UV Buildings • 173-MGD per Building GST • 230-MGD per Train*	UV • 4 UV Buildings • 173-MGD per Building GST • 230-MGD per Train*	UV • 4 UV Buildings • 173-MGD per Building GST • 230-MGD per Train*
Residuals Handling	UF Return to River • 4-MGD per Train* RO - 25% Recovery • 6.6-MGD per NF Building	C/S • 30 Trains* • 30 tons/day per Train* LS/F • 30 Trains • 77 tons/day per Train*	C/S/F • 28 Trains* • 32 tons/day per Train* RO - 25% Recovery • 6.6-MGD per NF Building	LS/F • 15 Trains* • 200 tons/day per Train*
Treatment Area	***120 acres***	***380 acres***	***160 acres***	***275 acres***
ADDITIONAL ITEMS				
Residuals Processing	Evaporation Ponds	Storage, thickening, and dewatering	Storqage, Thickening, Dewatering and Evaporation Ponds	Storage, thickening, and dewatering
Residuals Area	***21,100 acres***	***380 acres***	***21,100 acres***	***375 acres***
TOTAL AREA	**21,220 acres**	**760 acres**	**21,260 acres**	**650 acres**

*Trains are modularized treatment processes or components of a given capacity allowing practical construction and redundancy. Multiple trains are utilized to provide to entire project treatment capacity.

Performance and Operational Considerations

Table 5-9 presents a summary matrix of treatment performance and operational considerations for each alternative. Within this matrix, alternatives were scored on a point score scale of 1 to 3 (with 1 being best, 3 being worst) for each consideration. These considerations were then weighted based on a system impact factor between 1 and 3 (with 1 being least, 3 being most). Impact factors imply the level of impact the performance and operational consideration represents. This matrix is used to identify relative performance differences between the alternatives, with the lowest score performing the best. Note that this table does not factor in cost or environmental factors, which are discussed in later chapters. The performance and operational considerations used in the matrix are presented below:

Process Performance Removal: Each alternative will vary in its ability to remove the parameters of concern, which are included in the table.

Residuals Handling: Each alternative will require some type of residuals handling and disposal facilities. The type and quantity of residual will vary between alternatives as discussed previously.

Varying Raw Water Quality: Each of the alternatives can handle degradation in raw water quality to some extent without major modifications to the system. Each of the alternatives should also be able to handle the variations in seasonal water quality typical of surface waters.

Operation Complexity: Many of the processes will require a staff that has training in electronics, instrumentation and computers for the advanced automated processes. Several of the alternatives include processes that are likely unfamiliar to the staff. All of the supervisors, and at least some of the staff, should have specific training in the processes selected. Skilled workers with this expertise are more likely to be found near areas of higher population, such as Grand Junction.

Chemical Handling: Each of the processes requires the use of potentially hazardous chemicals. The chemicals include alum, ferric, polymer, lime, soda ash, carbon dioxide, caustic or sulfuric acid.

Process Reliability: All of the processes produce water of reliable quality. Each process is a continuous flow process and each can be designed to produce water continuously unless they are shut down for repair, maintenance or cleaning. Each of the processes has the ability to recover from some upsets or contaminants, but to varying degrees. Generally, those processes that have more unit processes are less reliable and more problematic.

Risk and Safety: Protection of employees and visitors to the proposed facilities is a concern, and is recognized as an important consideration.

Space Requirements: Available land space for alternatives is important as the land cost for treatment process and residuals disposal can drive the project.

Durability: Ability of a process to withstand abnormal operating conditions is important. Those alternatives that require more mechanical equipment will require maintenance of a regular nature. Those alternatives protected from hostile environmental conditions will be expected to last longer than those alternatives having equipment exposed to the elements.

Table 5-9: Treatment Performance and Operational Factors Summary Matrix

		Treatment Alternative Scores							
		1		2		3		4	
		UF/NF/UV		C/S/LS/F/UV		C/S/F/NF/UV		LS/F/UV	
	IF(1)	PS(2)	WS(3)	PS(2)	WS(3)	PS(2)	WS(3)	PS(2)	WS(3)
Process Performance Removal									
Turbidity	3	1	3	1	3	1	3	2	6
Hardness	3	1	3	2	6	1	3	2	6
Sulfate	2	1	2	3	6	1	2	3	6
TDS	2	1	2	2	4	1	2	2	4
Organics	1	1	1	2	2	1	1	3	3
Microbials	1	1	1	1	1	1	1	2	2
Subtotal			***12***		***22***		***12***		***27***
Operational									
Residuals Handling	3	3	9	2	6	3	9	2	6
Varying Raw Water Quality	3	1	3	3	9	2	6	3	9
Operation Complexity	2	3	6	2	4	3	6	1	2
Chemical Handling	2	2	4	2	4	2	4	1	2
Process Reliability	2	2	4	2	4	2	4	3	6
Risk & Safety	2	2	4	2	4	2	4	2	4
Space Requirements	2	3	6	1	2	2	4	1	2
Durability	1	2	2	1	1	2	2	1	1
Subtotal			***38***		***34***		***39***		***32***
Total Score (3)			**50**		**56**		**51**		**59**

Notes

1. System impact factors (IF) are ranked 1 to 3 with 1 being the least impact.
2. Processes are ranked with a point score (PS) from 1 to 3 with 1 being the best.
3. Weighted Scores (WS) equal IF x PS

Abbreviations:

UF – Ultrafiltration	UV - Ultraviolet Disinfection	LS - Lime Softening
NF – Nanofiltration	C/S - Coagulation/Sedimentation	F - Sand Filtration

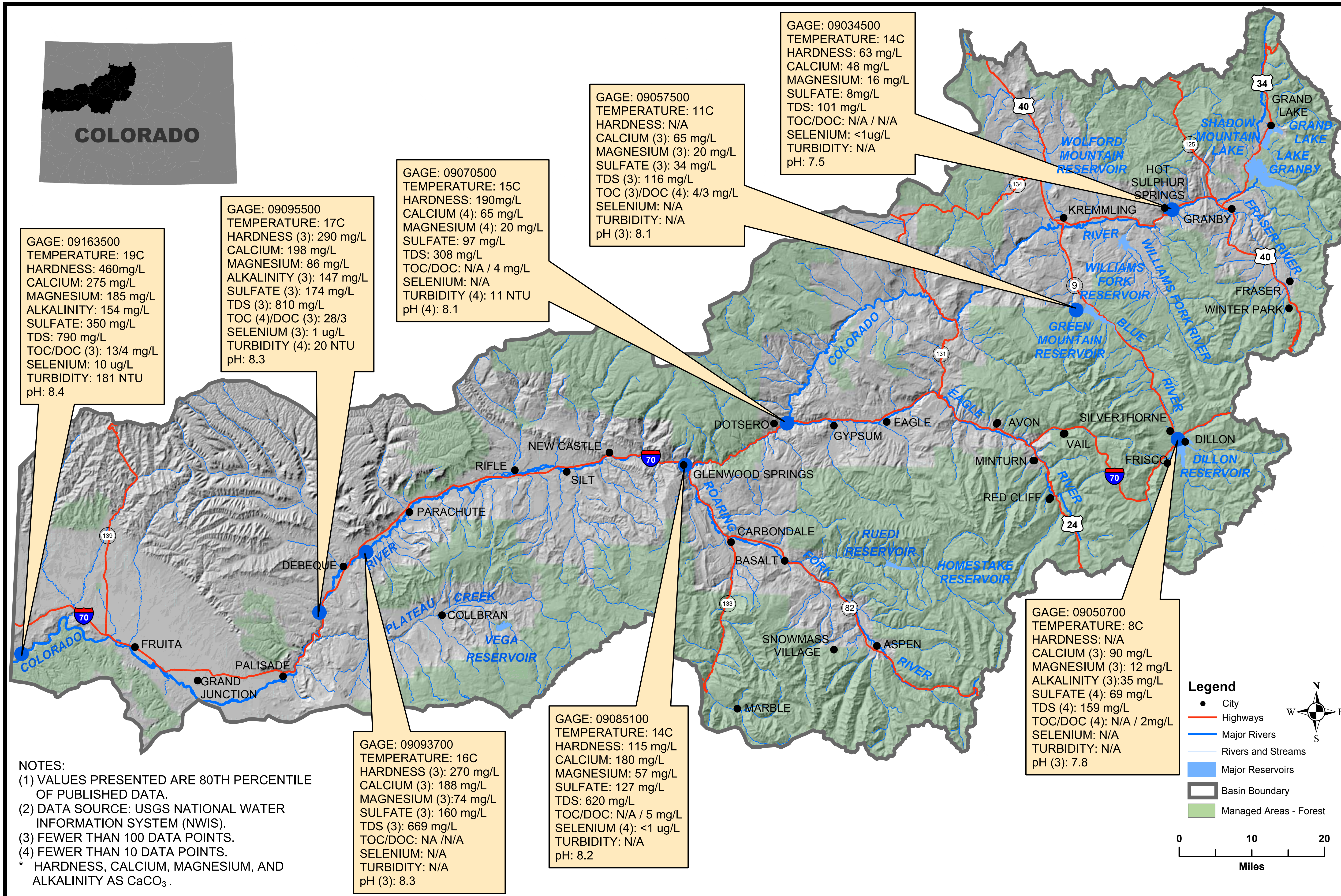
Alternatives 2 and 4 meet all of the requirements of treatment level one (drinking water quality) except for the reduction of sulfate, which would not be reduced below the secondary drinking water standard. Alternatives 2 and 4 fall well short of meeting the requirements of treatment level two (receiving water quality), as Chromium, Nitrate, Nitrite, Selenium, Sodium, Chloride, Sulfate and TDS would not be sufficiently removed.

Alternatives 1 and 3 meet the requirements of both treatment levels. The summary matrix, indicates that Alternative 1 was ranked as the best treatment process based on treatment performance and operational considerations, however the difference in scores between Alternatives 1 and 3 is very small.

Not included in the treatment level requirements are pesticides or herbicides, also known as synthetic organic compounds (SOCs). In general, a membrane barrier would provide the greatest potential for SOC reduction. Future studies would need to evaluate the effects of SOCs on treatment.

Conclusion

Some level of treatment is required to allow discharge of the project water to the delivery area. The alternatives for obtaining the treatment levels have been developed in sufficient detail for all planning level costs to be compiled. The costs for each project delivery capacity are developed in the next chapter along with the other project components.



NOTES:
(1) VALUES PRESENTED ARE 80TH PERCENTILE OF PUBLISHED DATA.
(2) DATA SOURCE: USGS NATIONAL WATER INFORMATION SYSTEM (NWIS).
(3) FEWER THAN 100 DATA POINTS.
(4) FEWER THAN 10 DATA POINTS.
* HARDNESS, CALCIUM, MAGNESIUM, AND ALKALINITY AS $CaCO_3$.

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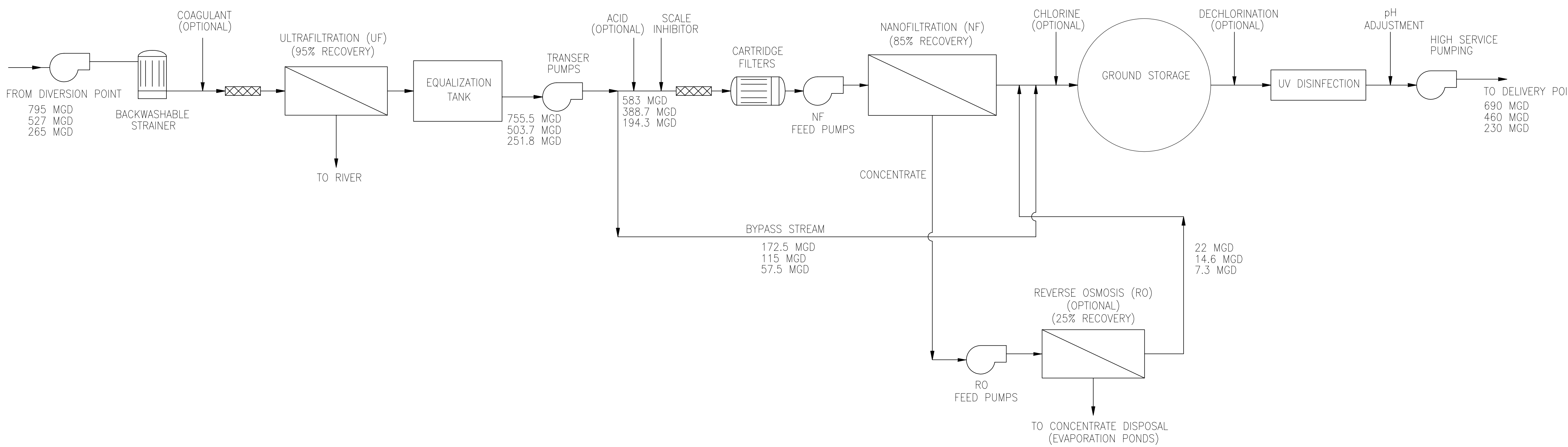
COLORADO RIVER RETURN RECONNAISSANCE STUDY

SELECT WATER QUALITY ON THE COLORADO RIVER

FIGURE 5-1

ALTERNATIVE 1: UF/NF/UV



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PROCESS FLOW DIAGRAM - ALTERNATIVE 1

FIGURE 5-2

DWG: Z:_DENVER PROJECTS\C72\501\CAD\PLAN SET\Process_flow_diagrams.dwg USER: mrau
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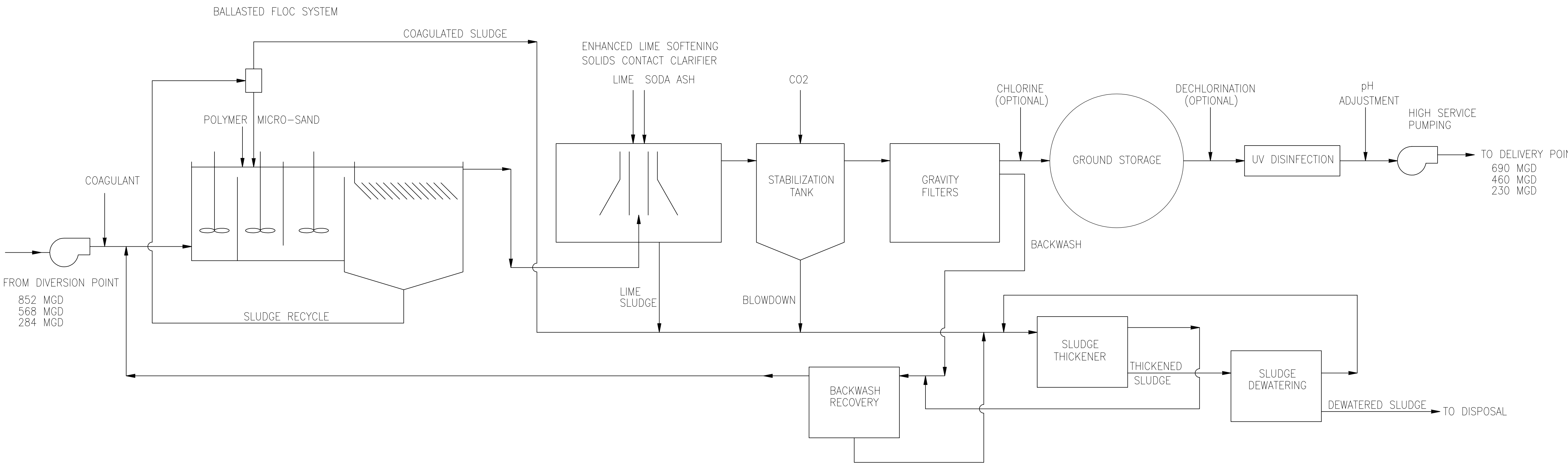
ALTERNATIVE 2: C/S/LS/F/UV



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PROCESS FLOW DIAGRAM - ALTERNATIVE 2

FIGURE
5-3

DWG: Z:_DENVER PROJECTS\C72\501\CAD\PLAN SET\Process_flow_diagrams.dwg USER: mrou
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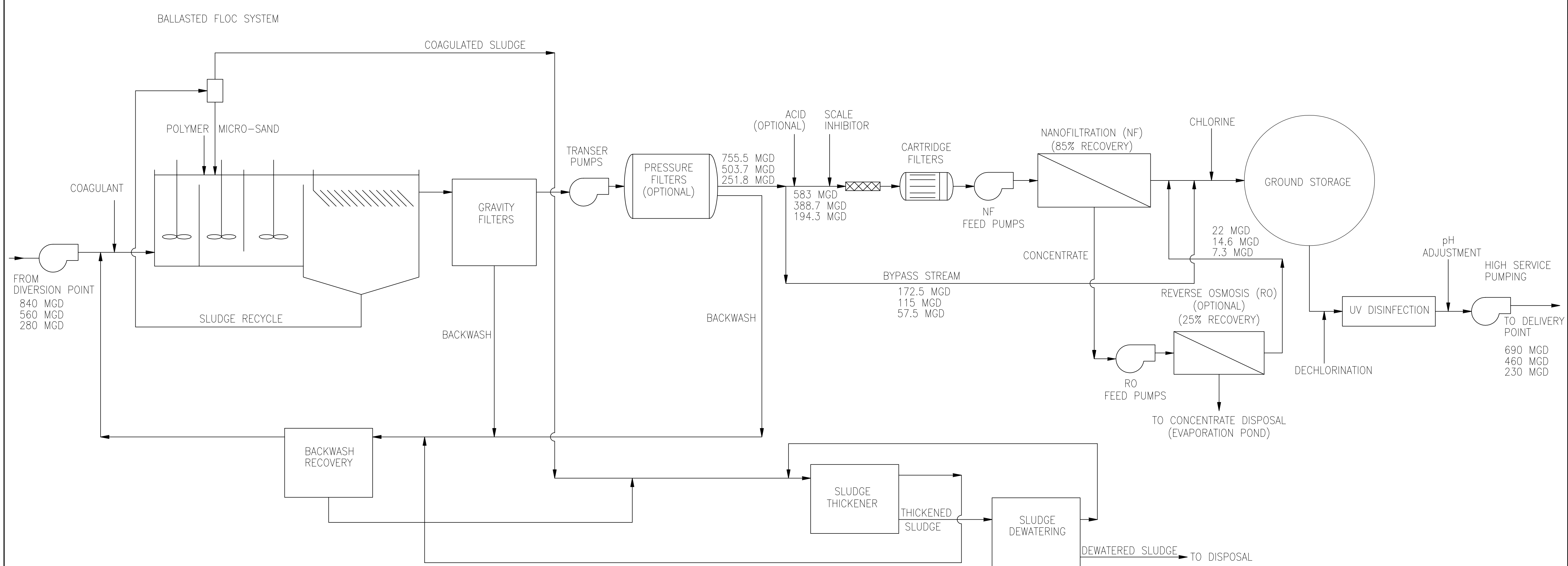
ALTERNATIVE 3: C/S/F/NF/UV



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PROCESS FLOW DIAGRAM - ALTERNATIVE 3

FIGURE 5-4

DWG: Z:_DENVER PROJECTS\C72\501\CAD\PLAN SET\Process_flow_diagrams.dwg USER: mrou
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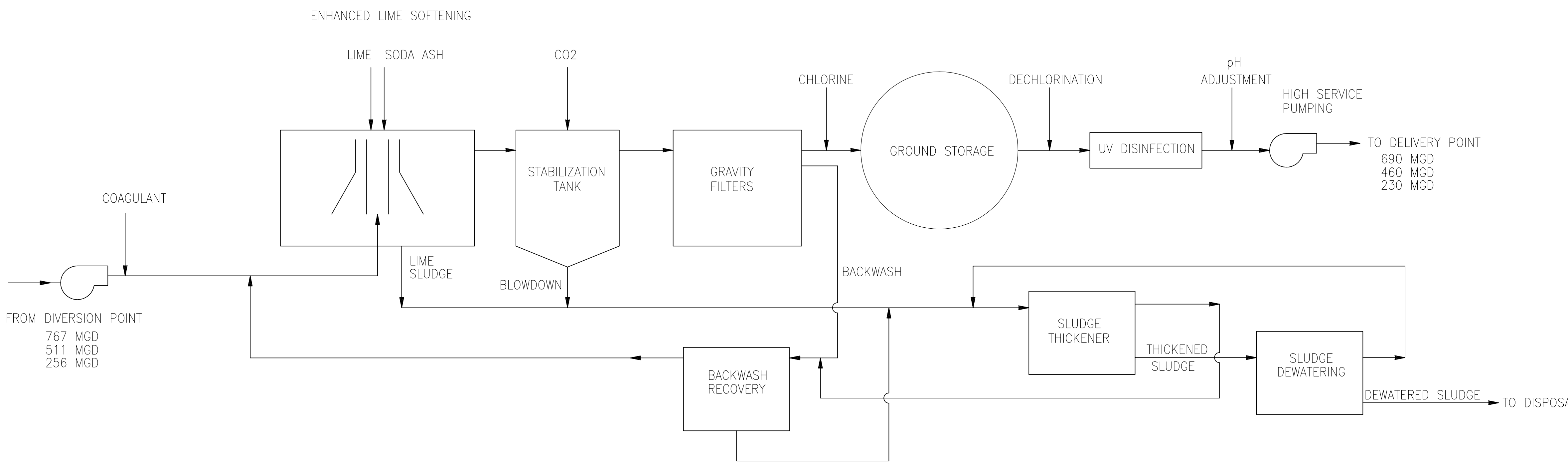
ALTERNATIVE 4: LS/F/UV



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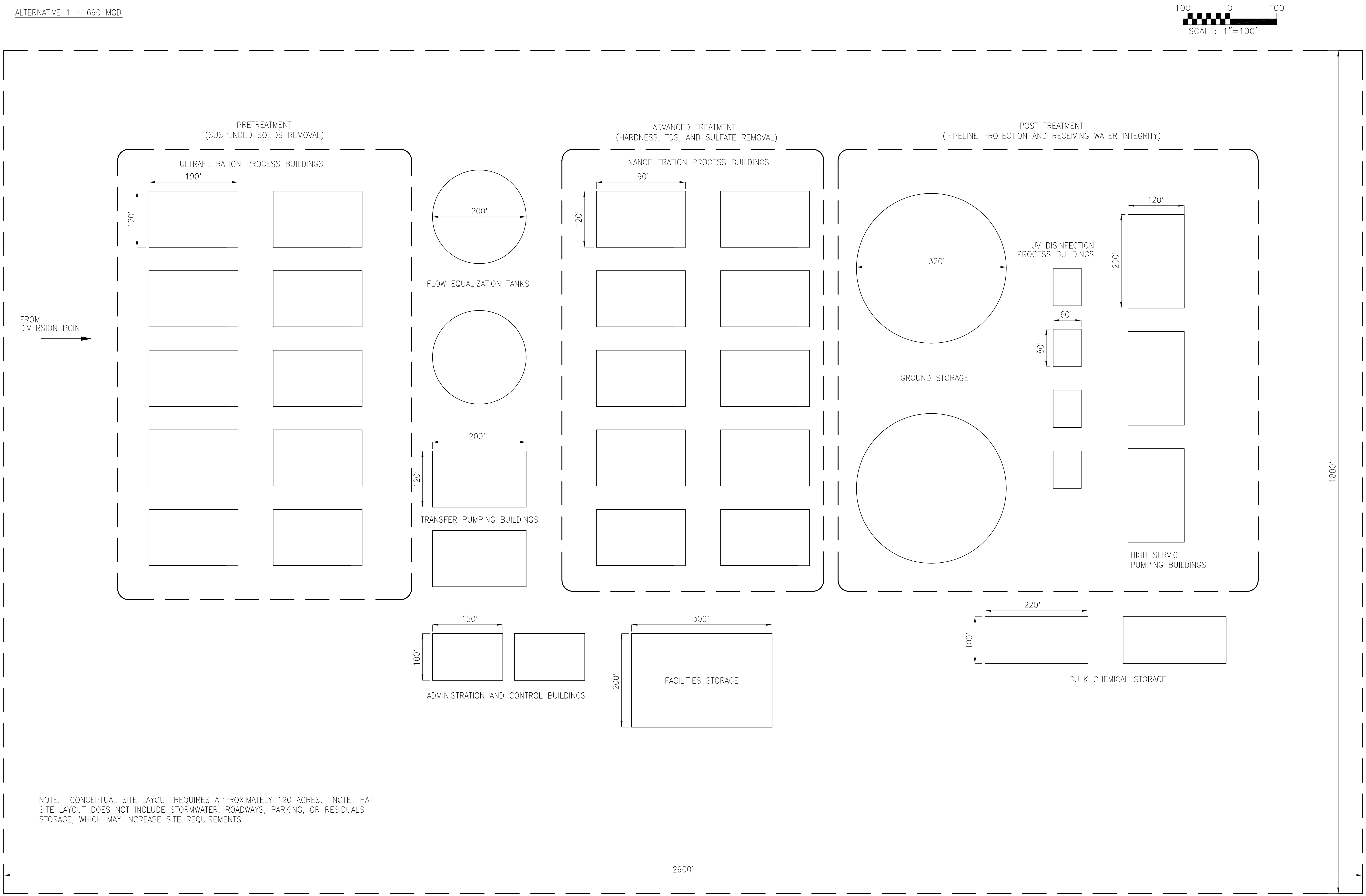
PROCESS FLOW DIAGRAM - ALTERNATIVE 4

FIGURE 5-5

ALTERNATIVE 1 – 690 MGD



NOTE: CONCEPTUAL SITE LAYOUT REQUIRES APPROXIMATELY 120 ACRES. NOTE THAT SITE LAYOUT DOES NOT INCLUDE STORMWATER, ROADWAYS, PARKING, OR RESIDUALS STORAGE, WHICH MAY INCREASE SITE REQUIREMENTS

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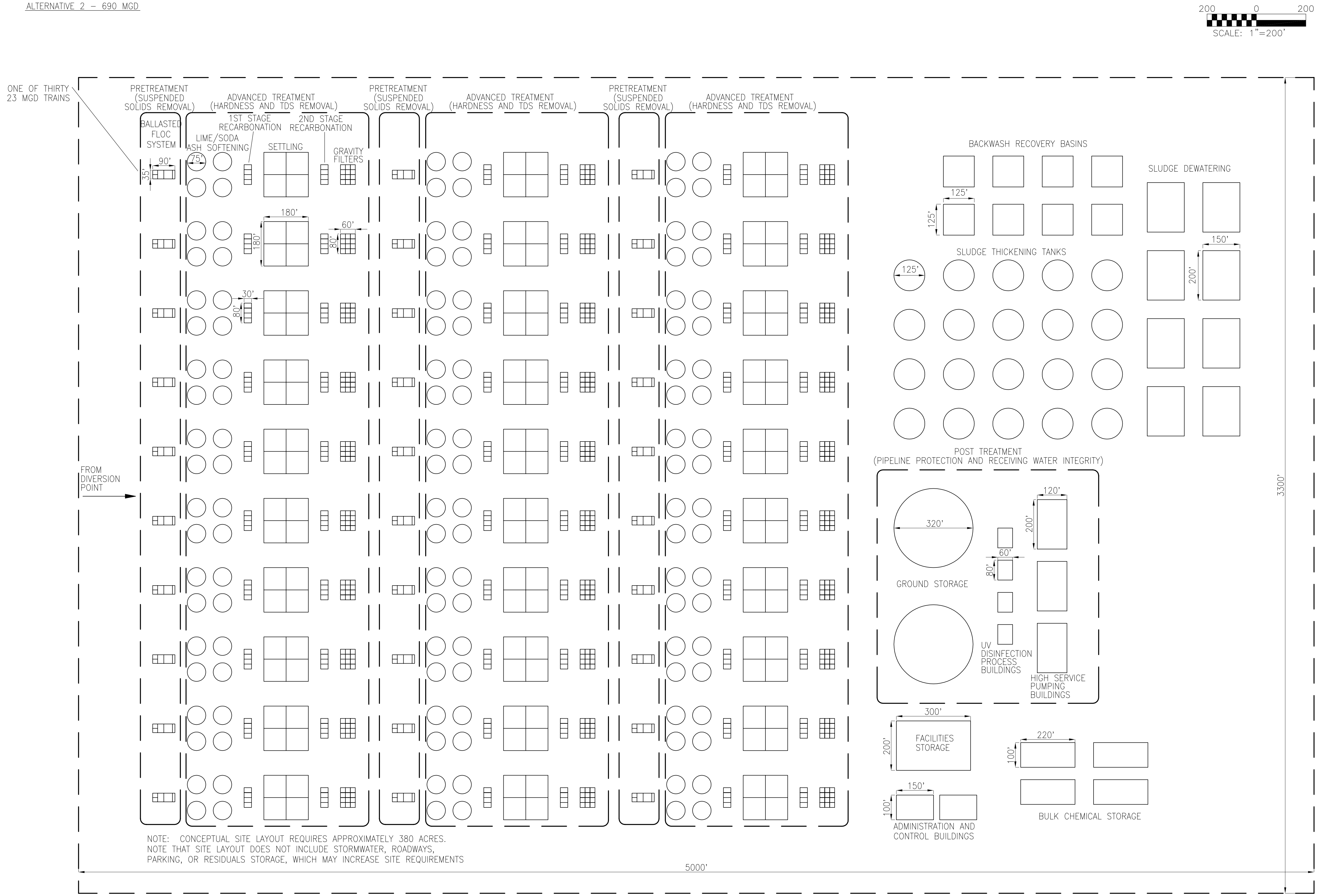
CONCEPTUAL SITE LAYOUT - ALTERNATIVE 1 - 690 MGD

FIGURE

5-6

ALTERNATIVE 2 – 690 MGD



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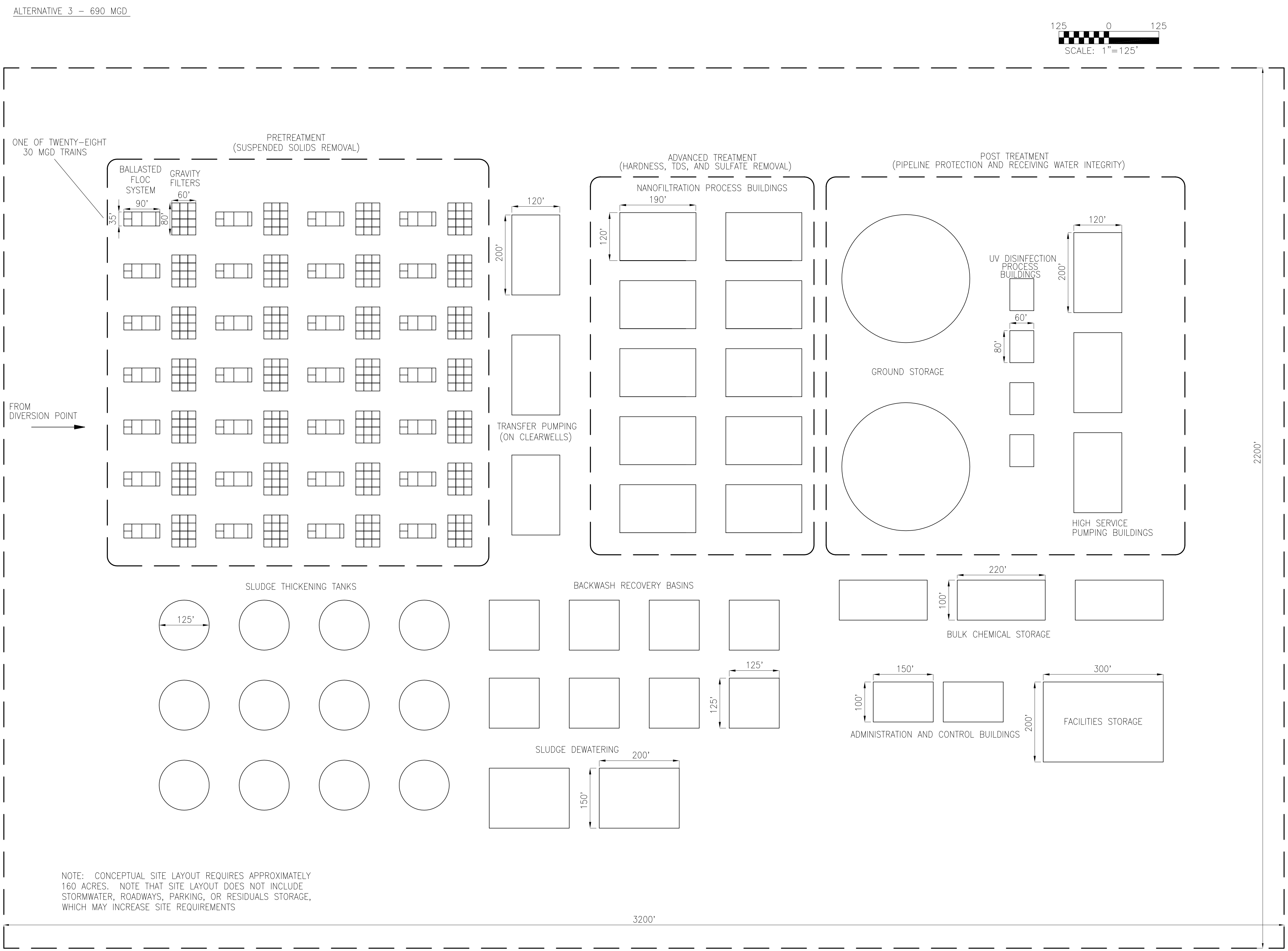
CONCEPTUAL SITE LAYOUT - ALTERNATIVE 2 - 690 MGD

FIGURE 5-7



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CONCEPTUAL SITE LAYOUT - ALTERNATIVE 3 - 690 MGD

FIGURE

5-8

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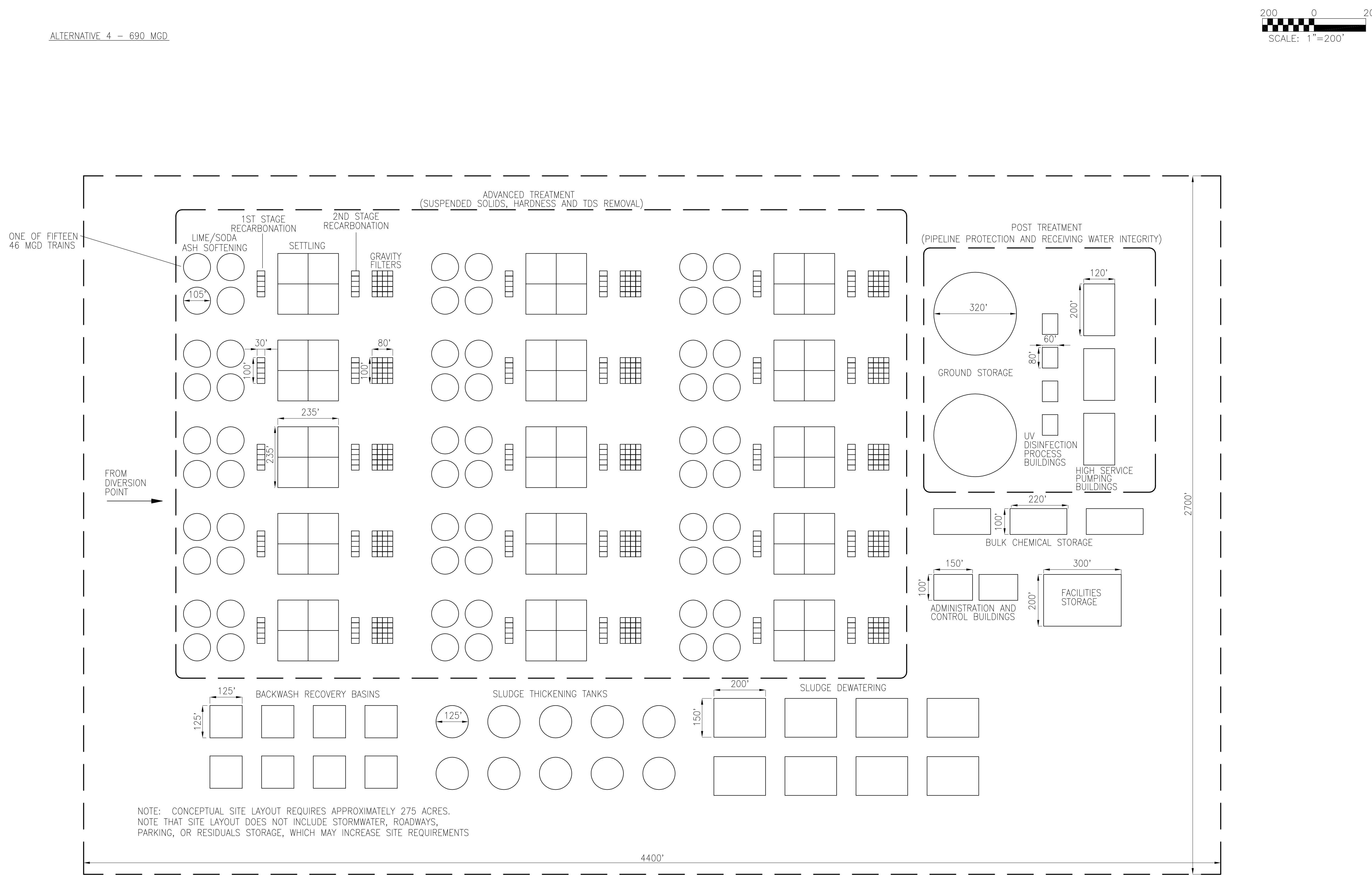
ALTERNATIVE 4 – 690 MGD



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CONCEPTUAL SITE LAYOUT - ALTERNATIVE 4 - 690 MGD

FIGURE 5-9