Benefits and Limitations of Utilizing A Raw-Water Blend Stream to Meet Production and Quality Goals at a Membrane Facility

James E. Christopher

Reverse-osmosis membranes were initially applied to the removal of salts, primarily sodium chloride, from brackish waters to create potable water from raw-water sources that previously could not be used for public supply. Membrane facilities were located in coastal areas where existing fresh groundwater supplies were inadequate to meet demands.

The brackish-water membranes used in these facilities generally reject 98 percent of most dissolved constituents in the raw water, producing a very pure but often highly corrosive water. Moreover, the quality of the permeate is a function of the concentration of constituents in the raw water, and the rejection of individual constituents cannot be selectively controlled as in the ion-exchange process.

The Safe Drinking Water Act Amendments of 1986 focused attention on the health effects of disinfectant byproducts and the removal of natural organic matter. A new group of "looser" softening (nanofiltration) membranes were developed and continue to be developed to provide a high rejection of organics and divalent ions, such as calcium, and a lower rejection of nonvalent ions, such as sodium and chlorides. The commercial availability of these membranes, coupled with the requirement to meet more stringent water quality regulations, has caused many communities to partially or completely replace their existing lime softening plants with membrane softening facilities.

These applications typically involve treating fresh, shallow groundwaters that are moderately to highly colored and hard, containing varying concentrations of iron. The nanofiltration (NF) membranes provide a high level of organic and hardness removal, but typically produce a soft water that is low in alkalinity and buffering capacity.

The solution to the aggressive membrane permeate produced by most membrane applications includes degasification to strip carbon dioxide to raise pH and lower caustic dosage, adding phosphate-based corrosion inhibitors and caustic or lime addition to recover alkalinity and raise pH to provide a stable water relative to calcium carbonate precipitation. The designer and operator are often faced with adding back constituents removed by the membrane process or not found in the raw water, at an increased operating cost to meet the finished-water quality goals and regulatory requirements.

Blending raw water or water from another process is a technique practiced in many membrane facilities to provide a mechanism to adjust the quality of the finished water. The quantity of blending is obviously limited by the constituents in the raw water, the finished-water quality goals, and the type of membrane. Blending capability offers the operator the flexibility to manipulate the quality of the finished water and should be considered for incorporation into any membrane facility.

The advantages of raw-water blending or sidestream treatment for blending with permeate may include any or all of the following:

- Reducing installed membrane capacity to achieve a given capacity
- Expanding plant capacity without increasing installed membrane capacity
- Fine tuning raw-water quality
- Reducing post-treatment chemical usage and cost
- Reducing pHs
- Increasing finished-water buffering capacity
- Reducing raw-water withdrawals for a given capacity

Three case studies illustrate the use of blending to take advantage of some or all of these benefits of blending with raw water or a treated sidestream.

Table 1
Existing Finished-Water Quality

pH	8.6
Alkalinity	30
Total Hardness	133
Calcium Hardness	106
Color	4.7
Chlorides	153
Iron	0.1

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City of Palm Bay South Regional Water Treatment Plant

The city of Palm Bay has an existing lime softening plant with a capacity of 10 million gallons per day (MGD) and a 1.65 MGD reverse-osmosis plant which provide potable water for the city's utility customers. The existing water treatment facilities are located in the northeast corner of Palm Bay, and growth is taking place in the central, south and western portions of the city.

The raw-water supply for the lime softening plant comes from the Surficial Aquifer, which is declining in quality and is highly maintenance intensive to maintain capacity; therefore, a new water treatment plant using the Floridan Aquifer as the raw-water supply is being constructed in the southern portion of the city. The plant will use reverse osmosis (RO) and a raw-water blend to provide the initial capacity of 4 MGD. The raw-water blend will be utilized to adjust the quality of the finished water to match the water quality from the existing treatment plant, minimize the installed membrane capacity, reduce operating costs, and reduce raw-water withdrawals.

The water quality goals for this project were established to meet all existing and anticipated water quality regulations and to be compatible with the existing finished-water quality. The key water quality parameters from the existing treatment plant are summarized in **Table 1**, based on operating data from January through November of 2001.

Raw water for the new South Regional Water Treatment Plant will be withdrawn from a series of Upper Floridan Aquifer wells. The water in the Upper Floridan Aquifer in the vicinity of the new facility is brackish, colorless, and moderately hard, and contains hydrogen sulfide. Brackish-water membranes will be used to reduce chlorides and TDS to meet regulatory limits and water quality goals. The average raw-water quality, projected permeate quality, finished-water quality goals, and maximum blend percentages are presented in **Table 2**.

Table 2
Projected Water Quality and Blending Analysis

Parameter	Floridan Aquifer Raw-Water Quality mg/L	Projected Permeate Quality mg/L	Finished-Water Quality Goal mg/L	Maximum Raw-Water Blend %
pH	7.6	5.9	pHs+0.1(>8.0)	100
Alkalinity	140	21	30-50	24.4
Total Hardness	680	18	120	15.4
Calcium Hardness	350	9	100	26.7
Color	<1	<1	<1	100
Sodium	345	79	130	19.2
Chlorides	850	59	160	12.8
TDS	1840	144	<450	18.0
Iron	<0.1	<0.1	<0.1	100
Fluoride	0.4	0.1	0.8	100
Hydrogen Sulfide	0.8	0.7	<0.1	0.0
Sulfate	200	30	<200	100

The blending analysis shows that no water can be blended, based upon the concentration of hydrogen sulfide in the water and the fact that if raw water blending is to take place, post treatment for hydrogen sulfide must be provided to meet the water quality goals.

The next constituent that limits raw-water blending is the concentration of chlorides. The finished-water quality goal for chlorides was increased to 160 mg/L from the existing average of 153 mg/L to allow for a higher blend percentage. The permeate was blended with 12.8 percent raw water, and the quality of the resultant blended water is presented in **Table 3**.

Table 3
Blended Water Quality

Parameter	Blended Water Quality mg/L	Finished-Water Quality Goal mg/L
pH	6.2	pHs+0.1(>8.0)
Alkalinity	36.2	30-50
Total Hardness	103	120
Calcium Hardness	52.6	100
Color	<1	<1
Sodium	113	130
Chlorides	160	150
TDS	361	<450
Iron	<0.1	<0.1
Fluoride	0.1	0.8
Hydrogen Sulfide	0.7	<0.1
Sulfate	51.8	<200

The results of blending the waters show that most water quality goals have been met, except that post treatment for pH, fluoridation and hydrogen sulfide must be provided. Although the blending has reduced the installed permeate capacity and has helped produce a quality similar to the existing, the calcium hardness will be lower than existing. Mixing the two waters in the distribution system will have to be evaluated, as well as the need for additional adjustment of the finished water.

City of North Miami Beach

The city of North Miami Beach is in the process of expanding its Norwood-Oeffler Water Treatment Plant to increase the capacity from 17 to 32 MGD in order to become independent from the Miami-Dade Water and Sewer Department water supply. The expansion program's other primary objective is to improve water quality for its customers, especially in terms of color and organics.

The expansion will consist of use of 15 MGD of existing lime softening capacity and construction of 6 MGD of RO capacity, 9 MGD of NF capacity, and 2 MGD of raw-water blend. The source of raw water for the RO facilities will be the Floridan Aquifer, and the raw-water source for the NF facilities will be the Biscayne Aquifer. The quality of finished water from the expanded water treatment plant will vary, depending on the quality of the source water, the treatment provided, the demand scenario, and the blending ratio. This situation is due to the three different processes used to treat two different water sources.

Raw water for the existing lime softening plant is withdrawn from the Biscayne Aquifer through a group of existing wells, and water for the proposed NF process will also be withdrawn from the Biscayne Aquifer from a new group of wells. The quality of the new wells is assumed to be similar to that of the existing raw-water supply; however, over time as the withdrawal rate is increased, a 10-to-20-percent increase in chlorides and color may occur.

The raw water from the Biscayne Aquifer is moderate in hardness, high in carbonate alkalinity, and higher in total organic carbon (TOC) and color. The moderate hardness requires some degree of treatment to reduce the hardness below 100 mg/L as CaCO3. The high carbonate alkalinity makes pH adjustment more expensive, since the water is well buffered against changes in pH. The higher TOC of the water mandates that chloramines be used to reduce disinfection by-products (DBPs). The higher color requires treatment to produce a finished water that is below the secondary standard for color, clear, and aesthetically pleasing to the consumer. Raw-water quality information is presented in **Table 4** for the Biscayne Aquifer.

Raw water from the Floridan Aquifer will be withdrawn from a group of wells that are under construction and testing. The expected raw-water quality is based on water quality from similar sources and data from initial testing. The Floridan Aquifer is generally considered to be a non-potable water source in the southeast region of Florida. The raw water is typically brackish, (high total dissolved solids [TDS], chlorides and sodium), hard, high in carbonate alkalinity, and containing a significant quantity of sulfides. The raw water is low in organic carbon and color and contains small amounts of naturally occurring ammonia and fluoride.

The primary treatment required for the Floridan Aquifer water includes the removal of chlorides, TDS, hardness, sulfides, sodium, and sulfates. The highest removal efficiency is generally required for chlorides, total hardness, and TDS to meet potable-water standards and water quality goals. Design raw-water quality information is presented in Table 4 for the Floridan Aquifer.

FINISHED-WATER QUALITY GOALS

The primary purposes of the proposed Norwood-Oeffler Water Treatment Plant

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Table 4
City Of North Miami Beach: Norwood-Oeffler WTP Expansion - Phase 1

Constituent	**Design Water Quality Values** Biscayne Aquifer	 Floridan Aquifer	 Lime Softened Water	 Low Pressure RO Permeate	 Nanofiltration Permeate[(1)]
pH	7.2	7.5	9.2	6.0	6.0
Alkalinity as $CaCO_{3,}$, mg/l	195	140	65	27	60
Total Hardness as $CaCO_3$, mg/l	215	1030	77	31	67
Calcium, mg/l	83.2	180	29.2	5.5	25.9
Magnesium, mg/l	1.7	140	1.0	4.1	2.2
Sodium, mg/l	19	1000	19	136	19
Chlorides, mg/l	40	2000	45	205	16
Sulfates, mg/l	21	300	20	15	25
Iron, mg/l	0.3	<0.1	.015	<0.1	<0.1
Fluoride, mg/l	0.2	0.1	0.2	<0.1	0.2
Nitrate, mg/l	<0.1	<0.1	<0.1	<0.1	<0.1
Color, NTU	35	<1	14	<1	1.0
Hydrogen Sulfide, mg/l	<0.1	0.5	<0.1	0.8	<0.1
Sulfide, mg/l	<0.1	1.3	<0.1	0.9	<0.1
Total Dissolved Solids, mg/l	405	3,820	270	395	160
Regulated VOC's, mg/l	BMCL	BDL	BDL	BDL	BDL
Regulated SOC's, mg/l	BDL	BDL	BMCL	BDL	BDL
Other Regulated Primary Inorganics	BMCL	BMCL	BMCL	BMCL	BMCL
Other Regulated Secondary Contaminants	BMCL	BMCL	BMCL	BMCL	BMCL

BDL: Below detection limit
BMCL: Below maximum contaminant level

Note:1. Finished water quality derived from the use of membrane projection software.

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expansion are to provide high-quality potable water to all the city's customers and to provide the capability to meet future water demands while meeting future regulations. In order to achieve these purposes, certain water quality goals were set for the proposed plant. At a minimum, these goals must comply with existing and proposed, but soon to be implemented, federal and state water quality regulations.

The finished water must be non-corrosive, without a tendency to leach metal ions in the transmission, distribution, or plumbing systems. A slight scale-forming water which will have a tendency to coat pipes with a thin layer of calcium carbonate is desirable to prevent corrosion and inhibit growth of bacteria. Softening or removing the hardness from water is required to reduce the tendency to scale hot-water pipes and heaters, reduce the tendency to scale and form soap scum on plumbing fixtures, reduce the amount of soap required to produce a foam or lather, and increase the effectiveness of detergents.

Hydrogen sulfide must be removed from the water, since it has a distinctive and objectionable odor which it can impart to the finished water. Hydrogen sulfide can also cause turbidity in the distribution system when oxidized to elemental sulfur in the presence of dissolved oxygen and chlorine; in the presence of sulfur oxidizing bacteria, it can also create corrosion problems as a result of the conversion of hydrogen sulfide to sulfuric acid.

The finished-water quality goals for the Norwood-Oeffler Water Treatment Plant are consistent with and more stringent than the projected water quality standards of the Florida Department of Environmental Protection and U.S. Environmental Protection Agency. The finished-water quality goals for all synthetic and volatile organic compounds have been set below the detection limits; therefore, the raw water must be free from these compounds to allow blending of raw water. The goals set for the primary inorganic ions will be 80 percent or less than that of the regulatory limit.

A total hardness of 40-80 mg/L was selected, based on the fact that this level is consistent with existing treatment results and will have a lower potential for scaling. A minimum alkalinity of 40 mg/L as CaCO3 was selected to limit post-treatment pH adjustment. The goal for chlorides was set at 100 mg/L, which is 40 percent of the regulatory standard. By selecting chlorides at this level, the amount of raw-water blend can be maximized, reducing the post-treatment pH adjustment costs.

The TDS of the finished water will be maintained at less than 350 mg/L, or 70 percent of the secondary standard. All other secondary water quality standards will be met. Finally, the finished water should have an average apparent color less than six color units and a maximum less than 10 color units, a turbidity less than 0.2 NTUs, iron less than 0.1 mg/L, hydrogen sulfide less than 0.1 mg/L, haloacetic acids less than 48 micrograms per liter, and total trihalomethanes less than 64 micrograms per liter. The maximum residual chlorine of 4 mg/L will not be exceeded in the finished water and a finished-water fluoride concentration of 0.8 mg/L will be maintained.

BLENDING SCENARIOS

The amount of finished water produced by lime softening, NF, and low-pressure RO will determine the quality of the finished water released into the distribution system. Preliminary design finished-water quality for each of the three treatment processes are summarized in Table 4. The finished-water quality of the NF and low pressure to permeate was derived from the use of membrane projection software.

To comply with the South Florida Water Management District permit conditions, a minimum base flow from the low-pressure RO treatment process of 5.0 MGD was utilized in the blending analysis. The utilization was increased up to 6.0 MGD as the demand increased up to the initial plant maximum-

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day design capacity of 32.0 MGD. The assumption was that as the duration of the demand decreased, the downtime for equipment failure, repair, or cleaning would decrease. To minimize finished-water color at lower demands, the NF process was assumed to operate at a minimum capacity of 6.0 MGD, or 2 skids. Similar to the low-pressure RO process, the capacity and utilization were increased up to the maximum of 9.0 MGD as the demand increased up to the initial capacity of 32.0 MGD.

The minimum capacity of the lime softening process was set at 3.9 MGD and kept below 10 MGD up to the average annual demand of 22.1 MGD to allow for maintenance of the hydrotreator units during low-demand periods and to maintain color below the finished-water quality goals. At the lower demands, a small quantity of blend water was utilized from the Floridan Aquifer to minimize color while recovering hardness and alkalinity. The use of this source as a blend was constrained by meeting the finished-water goal for chlorides.

The blend quantities determined in this manner and the resultant finished-water quality are summarized in **Table 5**, which shows that as demand rises, the color is expected to increase because of the increased use of the lime softening process. The increased color occurs primarily as the demand approaches the maximum-day demand; therefore, the customers will infrequently be provided this quality of water. All other water quality goals are met over the entire demand range.

Table 5
City Of North Miami Beach: Norwood-Oeffler WTP Expansion - Phase I
Preliminary Blending Flows and Quality

	Flows from Each Source, MGD					
Total Demand MGD	Reverse Osmosis Permeate	Nano-filtration Permeate	Lime Softened Water	Biscayne Aquifer Raw Water	Floridan Aquifer Raw Water	Alkalinity mg/L as $CaCO_3$
15	5	6	3.9	0	0.1	50.4
16	5	6	4.9	0	0.1	51.3
17	5	6	5.9	0	0.1	52.1
18	5	6	6.9	0	0.1	52.9
19	5.5	7	6.4	0	0.1	52.2
20	5.5	7	7.3	0	0.2	53.2
21	5.5	7	8.3	0	0.2	53.8
22	5.5	7	9.3	0	0.2	54.3
23	5.5	7	10.2	0	0.3	55.1
24	5.5	7	11.2	0	0.3	55.5
25	5.5	7	12.2	0	0.3	55.9
26	5.5	7	13.2	0	0.3	56.2
27	6	8	12.7	0	0.3	55.6
28	6	8	13.6	0	0.4	56.2
29	6	8	14.6	0	0.4	56.5
30	6	8.4	14.6	0.6	0.4	59.3
31	6	8.5	14.6	1	0.5	61.4
32	6	9	15	1.5	0.5	63.5

Note: 1. Blended Water Quality prior to post treatment

City of Sunrise Sawgrass Water Treatment Plant

The city of Sunrise recently completed the construction of its new Sawgrass Water Treatment Plant that withdraws water from the Biscayne Aquifer and treats it with NF. The plant was designed to treat 100 percent of the finished water using NF with a design recovery of 80 percent. The plant has an installed membrane treatment capacity of 12 MGD but is permitted to produce 9 MGD of finished water with one NF train out of service for reliability purposes.

Initial testing of the plant indicated that iron concentrations in the raw water were higher than anticipated and the removal of calcium hardness was higher than allowed by the specifications. The plant is capable of providing a high level of treatment through the use of NF, degasification, ozonation, and chlorination. The facility provides iron removal and softening by NF. It does not include provisions for blending raw water with the permeate or finished water.

The membranes were altered to reduce the rejection of divalent ions (iron, calcium, magnesium, etc.) in order to increase the hardness of the finished water. After the alteration of the membranes, it was discovered that finished-water iron concentrations were higher than the water quality goals and that calcium hardness concentrations were still lower than the specified concentration.

It was determined that using a raw-water blend would address the water quality issues, increase plant capacity, and reduce the quantity of groundwater withdrawals required to produce a given quantity of finished water. The blending of raw water will decrease the proposed withdrawals of raw groundwater from the Biscayne Aquifer.

Raw-water iron concentrations range from 1.45 mg/L to 2.10 mg/L. The current level of iron in the raw water is well above the secondary maximum contaminant level (MCL) of 0.3 mg/L. City officials have decided to remove iron to <0.1 mg/L for aesthetic purposes.

In order to remove iron using membrane treatment, other ions such as calcium are also removed, producing a soft, somewhat more corrosive finished water unless additional chemical facilities are provided at the end of the treatment process. Thus, the main factors in expanding the plant involve a balance between removing iron below 0.1 mg/L and retaining enough calcium so the water is least corrosive to the distribution system.

WATER TREATMENT GOALS

The original finished-water goals for quantity and quality as stated in the specifications are shown in **Table 6**.

The alkalinity and calcium hardness goals are dictated by corrosion control practices. The iron is governed by the secondary MCL. These goals are not attainable with the existing facilities; therefore, process modifications will be necessary to meet these goals and provide for the expansions.

Two options were examined to expand the capacity of the water treatment plant by blending raw water with the permeate product water. Each option requires the treatment of the raw water to remove iron only, so that the finished-water iron goals can be met and naturally occurring calcium and alkalinity in the raw water can be used to meet the stabilization goals. Each option also involves oxidation of the iron to form a precipitate that is then filtered from the system. In the first option the filtration method involves oxidation and greensand filtration, and the second option includes oxidation followed by ultrafiltration.

GREENSAND FILTRATION

Greensand filtration is a process used to remove manganese and iron. For iron removal, typically a continually regenerating (CR) process is used. The manganese

Table 6
Water Quality Goals

Parameter	Membrane Feed Water	Membrane Permeate Water
Flow (MGD)	11.25	9
Alkalinity, mg/L as $CaCO_3$	65 to 275	40-80
Calcium Hardness, mg/L as $CaCO_3$	250	40-80
Iron, mg/L	1.5	<0.3

Table 7
Oxidation and Green Sand Filtration Raw-Water Blend Treatment

Description	Quantity	Units	Unit Cost ($)	Total Cost ($)
Green Sand Filtration Units (3 MGD)	2	EA	$1,600,000	$3,200,000
Backwash Facilities	1	LS	$125,000	$125,000
Piping, Valves, and Fittings	1	LS	$150,000	$150,000
Electrical/Instrumentation	1	LS	$200,000	$200,000
Chemical Feed Improvements	1	LS	$150,000	$150,000
Total				***$3,835,000***

Note: Conceptual Cost prepared for comparison basis only.

greensand CR process is applicable on well waters where iron removal is the main objective, with or without the presence of manganese. Waters having iron concentrations in the range of 0.5-3 mg/L would have run lengths of 18 to 36 hours at a design flow rate of 3-5 gpm/sf.

The CR process involves feeding an oxidant or combination of oxidants, such as potassium permanganate and chlorine, to raw water prior to contact with the manganese greensand bed. Chlorine, which is recommended, should be fed at a suitable distance prior to the potassium permanganate injection point. The chlorine will oxidize the bulk of the iron and any sulfide. Potassium permanganate will then complete the oxidation of trace amounts of iron and soluble manganese.

The manganese greensand bed performs a dual function to complete the removal of iron and manganese. First, correct operation of a CR filter requires that a slight excess of permanganate, indicated by an influent water having a light orange color, will insure that the oxidant demand has been met, whether using permanganate alone or in combination with chlorine. Any slight excess permanganate will be reduced to a manganese oxide by the manganese greensand. The manganese oxides will then precipitate on the grains, maintaining them in a continually regenerated state.

Conversely, a temporary underfeed of oxidant would utilize the oxidizing capacity of the regenerated manganese greensand to complete the oxidation of iron and manganese as required; therefore, in the CR process, the manganese greensand acts as a redox buffer with capabilities of both oxidation and reduction as required by influent water conditions. Second, it is a well-known fact that in iron and manganese removal by oxidation, the presence of manganese oxide will act as a catalyst, whether the oxidizing agent is oxygen, chlorine, ozone, or permanganate, ensuring that the reaction goes rapidly to completion.

It was determined from literature review that 98-percent removal of iron can typically be achieved through the use of greensand filtration. This would reduce a raw-water iron concentration from 2 mg/L to 0.04 mg/L, which is well below the secondary MCL, and would reduce the iron concentration in the blended finished water. If only the raw-water blend were treated, the greensand filters would treat a small portion of the overall plant flow—approximately 3 MGD. **Table 7** presents costs for the 6 MGD installed and 3 MGD firm-capacity greensand filtration option. **Figure 1** represents the resultant water quality for treatment of a 20-percent blend of raw water with greensand filtration.

TABLE 8
Oxidation and Ultrafiltration Raw-Water Blend Treatment

Description	Quantity	Units	Unit Cost ($)	Total Cost ($)
Ultrafiltration and Associated Manufacturer Supplied Equipment	1	EA	$4,200,000	$4,200,000
Additional Ancillary Plant Costs	1	LS	$3,000,000	$3,000,000
Chemical Feed/Oxidation Improvements	1	LS	$150,000	$150,000
Total				***$7,350,000***

Ultrafiltration

Membrane processes that have applications in drinking-water treatment include reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), microfiltration (MF) and electrodialysis reversal (EDR). UF is a pressure-driven filtration process that utilizes hollow-fiber membranes capable of separating both insoluble and soluble materials from the treated water. Hollow-fiber membranes are either "inside-out" cross-flow membranes or "outside-in" transverse-flow membranes. The applied pressure utilized with UF processes is much lower than feed pressures for NF or RO processes and is referred to as the transmembrane pressure.

UF has been shown to be very effective for particle and turbidity removal. Turbidity can be lowered to below 0.05 nephelometric turbidity units on a consistent basis for a variable feed water quality. Coliforms, bacteria, viruses, and cysts can be effectively removed from a water supply by UF.

For the purpose of this analysis, Zenon was contacted regarding UF performance. The company's ZeeWeed® ultrafiltration membrane is oxidant resistant and operates well in the presence of high solids. As a result, the process is efficient in treating water sources containing high levels of turbidity, iron and manganese.

The process for a ZeeWeed® plant treating iron and manganese consists of a simple preoxidation step, followed by ultrafiltration. With the zenon process, the ultrafilter cassettes are immersed in the water and a pump is used to draw a vacuum through the membrane to produce permeate.

Ultrafiltration is not susceptible to oxidants and Zenon has successfully used a number of oxidants to aid in the removal of iron. UF was evaluated for treating the bypass blend only; therefore, the only options investigated for UF are for treating between 3 MGD and 6 MGD of raw-water bypass. **Table 8** presents costs for providing a 6-MGD UF facility provided with pre-oxidation.

SUMMARY

After a review of economic and technical feasibility for the different treatment techniques, the recommended course of action for the city is to use a raw-water bypass treated with greensand filtration to blend with the nanofiltration permeate water. Although the ultrafiltration with preoxidation provides a high-quality water with very low concentration levels of iron, the total capital cost for this project using UF is greater than that for using greensand filtration. The UF costs did not include concen-

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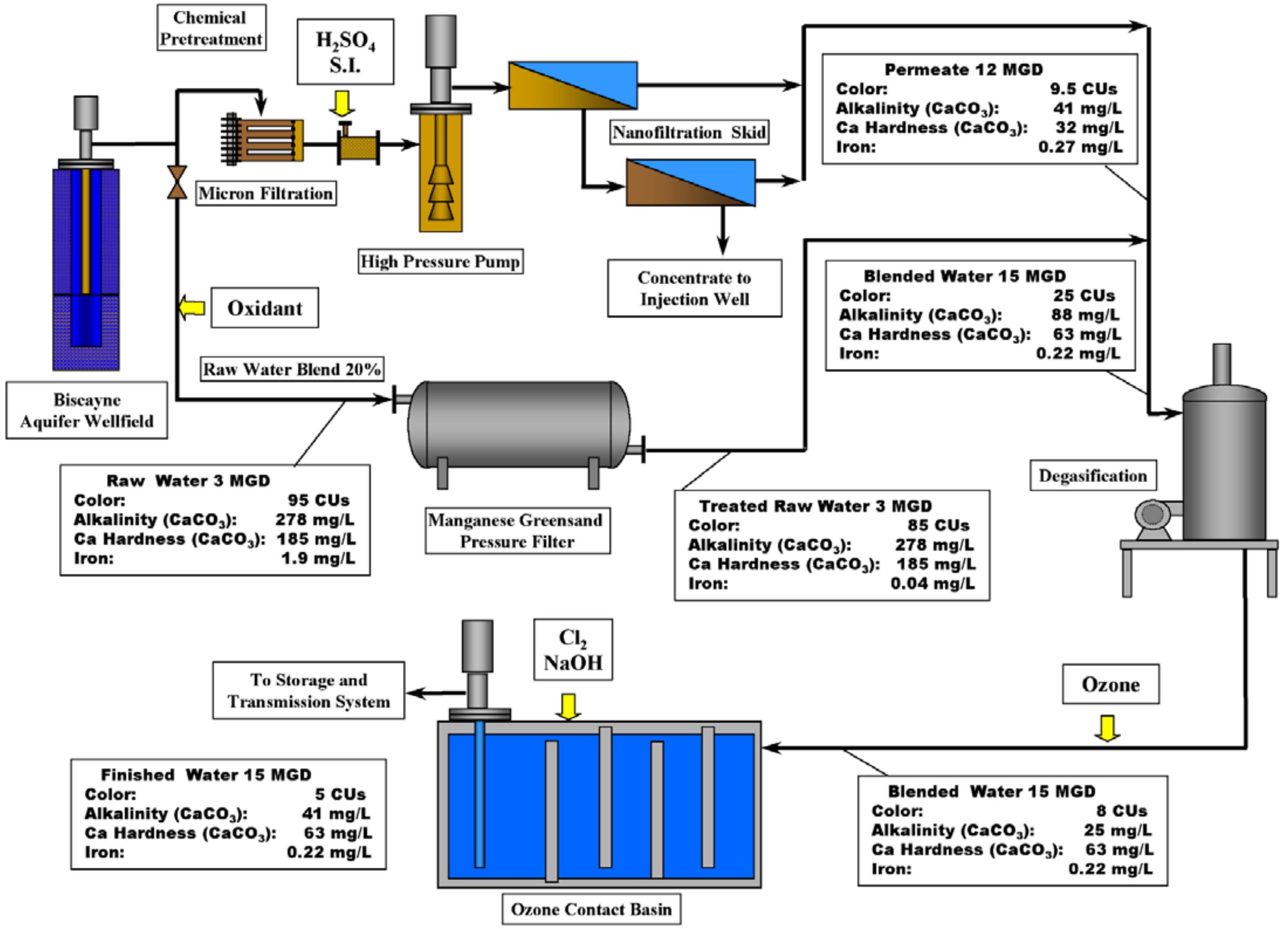

Figure 1

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trate disposal faculties that could also significantly impact the cost unless discharge to the sewer system was an option.

The cost associated with providing two 3-MGD greensand filtration units and the necessary chemical feed equipment for oxidation for this option is estimated to be $3.835 million. Figure 1 clearly shows that the blending of the treated-water bypass with the nanofiltration permeate allows the facility to be expanded without increasing installed membrane capacity and meets all the original water quality goals.

Conclusions

Successful blending requires a knowledge of the expected quality and variations of the raw-water, permeate, and other treated-water streams and the development of specific water quality goals. Limiting constituents must then be determined to calculate minimum and maximum blending ratios and to adjust finished-water quality goals to maximize their attainment.

The examples in this article illustrate the ability to blend raw and treated water from multiple sources to meet finished-water quality goals or to reduce membrane post treatment chemical addition to meet these goals. This is especially true where the objective is to meet the minimum regulatory requirements and providing the highest purity water is not the prime objective. Blending in combination with the use of reverse-osmosis treatment provides a viable alternative to reduce raw-water withdrawals, chemical usage, and operating and capital costs while providing a method to vary finished-water quality.