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Lopez Water Treatment Plant Evaluation Report

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Section 1: Introduction and Summary

1.1 Background

The San Luis Obispo County Public Works' (SLOC PW) Lopez WTP is a 6 million gallon per day (MGD) treatment plant treating surface water from Lopez Reservoir. The Lopez WTP was recently updated, and the new treatment process consists of coagulation, flocculation, and dissolved air floatation (DAF) clarification, disinfection with chlorine dioxide, low-pressure membrane filtration with PALL MF membranes, and additional disinfection with free chlorine. The modified Lopez WTP has significantly more automation and a new supervisory control and data acquisition (SCADA) system to monitor and control the treatment processes.

The new Lopez WTP facilities began operations in June 2007. Plant staff has experienced what they feel is an excessive number of operational and control challenges during the first six months of operation. While it is common for new facilities to require operational adjustments during the plant start-up process, the number of plant alarms, the sensitivity of the new facilities to flow changes, and the operational issues have been very frustrating for the Lopez WTP staff.

SLOC PW has been working with the project's Design Engineer, Black & Veatch (B&V), and with the membrane system supplier, PALL Corporation, to understand and address the on-going operational challenges at the Lopez WTP for the past six months. SLOC PW hired Kennedy/Jenks in early 2008 to provide an independent assessment of the operating issues and identify potential modifications to the control strategies, or to the plant, to improve overall plant operations.

1.2 Plant Operational Issues

The primary issues/concerns with the Lopez WTP that Kennedy/Jenks was requested to evaluate include:

- The overall plant flow balance and issues with control of filtered water chemical addition
- Scaling that is occurring on the strainers and MF membranes
- The MF membrane system requires more frequent cleaning than was anticipated
- The greater than expected quantity of waste cleaning solution is impacting sludge drying bed operation
- The chlorine dioxide residual is difficult to maintain through the contact basin
- The hydraulic conditions downstream of the MF filters entrain air into the filtered water

1.3 Report Objective

Kennedy/Jenks reviewed select design drawings and documents, equipment submittal information from PALL Corporation, and correspondence between SLOC PW and the Design Engineer and PALL on the above issues. Kennedy/Jenks met with Lopez WTP staff and toured the Lopez WTP facilities on 31 January 2008. Kennedy/Jenks prepared a draft report and received review comments from SLOC PW staff, and conducted follow-up phone interviews with Lopez WTP staff in June 2008.

This report briefly describes each of the above issues of concern and provides Kennedy/Jenks' evaluation of the situation and recommendations to address the operating issues. Some of the issues are inter-related and are discussed in more than one section.

1.4 Report Summary

This section briefly summarizes the recommend improvements, and the associated opinions of probable cost, that Kennedy/Jenks' believes would improve the operational performance of the Lopez WTP. The recommended improvements are discussed in greater detail in the body of the report.

The opinions of probable capital cost are planning levels and have an accuracy based on guidelines from the Association for the Advancement of Cost Engineering (AACE) of –30 to +50-percent. The estimates reflect 2008 dollars and planning level accuracy. A total of 45 percent is added to the estimated cost to provide an allowance for taxes (8 percent), General Contractor overhead and profit (12 percent), and contingencies (25 percent). Additional project costs for engineering and construction management were not included. Some of these projects could be done by SLOC Public Works staff or as contract work directly with specialty contractors, thereby reducing the total project cost.

Recommended Improvements for Operational Performance, Flow Control and Chemical Addition

Recommended Improvement	Benefit	Opinion of Probable Capital Cost
Relocate Chlorine Addition point. Relocate WQ7 Sample Point and add a sample pump (Section 2.7)	Achieve better mixing an permit sampling of feed Chlorine residual	$5,000
Program and optimize residual feedback compound loop control for chlorine and ammonia feed. (Section 2.7)	Provides improved chemical feed control with variable flow.	$15,000
Increase MF Feed pump wet well by expanding into (E) recarbonation chamber No. 1. (Section 2.4)	Provides more time for SCADA control of plant inlet flow.	$50,000
Provide dedicated filtrate flow meter (Section 7.5)	Eliminates potential inaccuracies and errors with calculated flow rate.	$30,000

Recommended Improvement	Benefit	Opinion of Probable Capital Cost
Add 6 additional elements to each MF rack. (Section 4.6)	This will lower the average flux of the MF units by 10% and help reduce fouling rates.	$60,000 (assuming $2,000 per element)
Program the SCADA system to reduce the overall plant flowrate setpoint during periods when a MF unit goes into a longer term shutdown for an EFMC or integrity test (Section 2.5)	This should help the front end process control and help to not to over-flux the remaining operational units.	Potentially provided by Black and Veatch at no cost as part of their SCADA programming for the project.
Request revised written control strategies for the project to include changes to the control strategies that have been made during the startup process. (Section 2.2)	This will provide the Lopez WTP Staff have a clear understanding and record of the design and programmed plant control strategies.	Potentially provided by Black and Veatch at no cost, under provision for record documents for project.
Package NF Softener System for high pH CIP solution make-up water. (Section 4.6)	Reduce scaling of membranes during high pH cleanings.	Potentially provided by Pall Corporation at no cost.
Continue to use free chlorine pre-oxidation of the source water on a regular basis (Section 6.4)	This will help maintain the chlorine dioxide residual by reducing demand.	No capital cost since system is already in operation.
Discuss with PALL and switch to hydrochloric acid for acid cleanings. (Section 5.4)	This would reduce the organic levels in the spent cleaning solution waste.	No capital cost and potentially lower O&M cost.
Subtotal		**$160,000**
Contingency, OH&P @ 45%		$75,000
Total		**$235,000**

The following table summarizes additional improvements, and the associated opinions of probable cost, that would help improve the hydraulic conditions and reduce the scaling at the Lopez WTP. The additional improvements are discussed in greater detail in the body of the report.

Additional Improvements for Improved Hydraulics, Water Quality and Scaling Control

Additional Improvement	Benefit	Opinion of Probable Capital Cost
Construct a hydraulic control standpipe on the filtered water pipeline. (Section 7.5)	This will prevent contaminants from being drawn into the filtered water pipeline.	$90,000
Carbon dioxide acid addition system (Section 3.4)	Reduce water pH and formation of calcium carbonate scale.	$400,000
Subtotal		**$490,000**
Contingency, OH&P @ 45%		$220,000
Total		**$710,000**

The conceptual design and costs for a potential pellet softening system for the Lopez WTP are described in Section 3 and in a Technical Memorandum (TM) titled “Conceptual Design and Opinion of Cost for a Pellet Softener System” for more details on. The TM is provided as an attachment to the report. The conceptual level of probable cost for a 4.5 MGD pellet softening system is in the range of $7 to $8 million.

Section 2: Plant Flow Balance Issues

2.1 Background

The source water to the Lopez WTP flows by gravity through a modulating butterfly valve (control valve), a flow meter, the Dissolved Air Floatation (DAF) process units and the chlorine dioxide contact basin. At the end of the contact basin, the water flows over a weir into the MF Feed Pump Wet Well. From the MF Feed Pump Wet Well, water is pumped through the strainers and MF filters and then flows by gravity into the clearwell.

The Lopez WTP has five (5) low-pressure MF membrane skids manufactured by Pall Corporation. Each skid has a nominal capacity of approximately 1.4 MGD to provide the plant design capacity of 6 MGD. During plant operation, when a MF skid goes into backwash (~2 to 3 minute duration), integrity test (~10 to 12 minute duration), or Extended Flux Maintenance Clean (EFMC) (~30 to 45 minute duration), the flow through that MF unit stops. If the source water flow rate into the plant is not reduced, the water level in the MF Feed Pump Wet Well will begin to rise. The MF Feed Pump Wet Well is relatively small and has a limited capacity to accommodate the increasing and decreasing water level caused by the starting and stopping of the MF filters. These stops and starts of the MF units have created overall plant flow rate control difficulties and have resulted in frequent alarms for the plant systems.

The Design Engineer for the new Lopez WTP facilities provided the overall SCADA programming for the plant. Pall Corporation provided the programming for the MF system. The Pall and overall plant control programs need to be carefully coordinated to ensure the proper operation of both the overall facility and the membrane system. The Design Engineer SCADA programmer, the Lopez WTP Operations Staff and the Pall programmer have been working together over the past six months to resolve the flow rate and control issues.

2.2 Lopez Plant Control Strategies

Kennedy/Jenks' review of the design drawings and specifications for the project, and discussion with Lopez WTP Staff, found that basic written control strategies for the project are included in Section 13550 of the Project Contract Documents. The Process and Instrumentation Drawings show signals going to the PLC but do not show how each treatment process/system is controlled. The written control strategies are important and provide guidance to the SCADA programmer and to plant staff on how the plant systems are intended to operate and be controlled.

Written control strategies are typically provided for every piece of equipment or system that is controlled by, or interacts with, the SCADA system. Control strategies generally include a brief narrative description of the control of the system, the modes of control, the different instruments (flow meters, level signals, etc.) that provide inputs to the control of the system, the setpoints of the system and alarms. Kennedy/Jenks has provided some example control strategies from a membrane water treatment plant project to show what is typically provided. The example written control strategies are in Appendix A.

Kennedy/Jenks recommends that SLOC PW request that the design engineer provide revised written control strategies for the project to include changes to the control strategies that have been made during the startup process. This will provide the Lopez WTP Staff with a clear understanding and record of the design and programmed plant control strategies.

From our discussions with plant staff, we understand that the general plant control strategy is as follows:

- The Plant Operator enters a desired plant flowrate setpoint
- Plant inlet control valve modulates to meet flowrate setpoint based on influent flow meter
- MF Feed Pump Wetwell level provides throttling control of inlet control valve (flow) if level gets too high (exceeds a setpoint)
- MF system operates MF pumps and MF filters to meet a filtered water flow rate setpoint. The MF filtered water flow rate is based on sum of calculated MF filtrate from MF inlet flow meters (no combined filtrate flow meter is provided)
- MF Feed Pump Wetwell level provides additional control of MF system if level gets too high or low
- If one or more MF units stop, the other MF units increase production to meet plant flowrate setpoint by modulating their inlet modulating valve.
- Inlet Flow meter was recently integrated to the Feed Pump controls to prevent pump cycling

2.3 Instrument Technician/SCADA Programmer

During our site visit, SLOC PW Staff asked about adding an Instrument Technician/SCADA Programmer to the plant staff.

New water treatment plants in general, and membrane facilities in particular, often have significantly more instrumentation and programmable logic controller (PLC) components that require specialized expertise to maintain, calibrate, trouble-shoot and repair. This is the case for the new Lopez WTP.

While these services could be contracted out, service companies may not be able to respond to plant emergencies on short notice. In addition, while most instruments required regular maintenance every six months, certain instruments such as chlorine analyzers require attention weekly. Many plants of this complexity employ a technician who also has expertise in electrical wiring and motor controls. This helps trouble-shooting routine events such as motor trips, fuse replacement and small wiring installations.

There are many PLCs at the Lopez plant that require attention, such as replacing faulty modules, identifying short circuits and verifying proper signals to SCADA. It would be beneficial to have technicians with experience in computer system and software development.

Kennedy/Jenks recommends that SLOC PW hire an Instrument Technician/SCADA Programmer to provide operations and maintenance support to the instruments and PLC systems in the new facility. This Instrument Technician could also be a technical resource to help maintain instrumentation at other water, wastewater or other facilities with PLCs and instrumentation. If a qualified full time position could not be filled immediately, a part time person could fill this position until the position could be filled permanently.

2.4 Inlet Flow Control Issues

The MF feed pump wet well is undersized and is contributing to plant flow balance challenges on the feed side of the MF filters. Based on the Lopez WTP design drawings, the MF feed pump wet well is approximately 19 feet long and 7.5 feet wide. The wet well is hydraulically connected to the end of the chlorine contact basin beyond the control weir. This provides a wet well capacity of only approximately 1,990 gallons per foot of wet well operational depth. The drawings show a minimum water level in the wet well at 317.67 ft and an overflow at 322.25 ft – giving an operational volume of only approximately 8,400 gallons. At a plant flow rate of 6 MGD (4,200 gpm), this provides very little cushion for the plant SCADA system to adjust flows to maintain level within a set-point band and at best only gives two minutes of response time to make changes. The upstream processes do not handle sharp increases and decreases in flow well and the small wet-well impacts the ability to efficiently operate the plant.

Additional MF feed pump wet well volume could be achieved by expanding the wet well into the “recarbonation chamber” portion of the existing sedimentation basin to the north of the MF feed pump wet well. Depending on the specific configuration of the “recarbonation chamber”, the volume and response time for system controls could be increased two to three times by connecting the two areas. This could be a relatively simple modification involving connecting to the two basins and providing a section of pipe to ensure water does not stagnate at the far end of the wet well. The recarbonation chamber could be covered but would not necessarily need to be.

2.5 Flow Control Potential Impact on MF Filters

The Lopez WTP has five (5) low-pressure MF membrane skids (or units) manufactured by Pall Corporation. Each skid has 58 membrane modules and spaces for 6 additional modules. Each membrane module (or element) has 538 ft^2 of exterior membrane surface area (outside-in flow path). With 58 MF modules, each skid has 31,240 ft^2 of membrane area. According to Lopez WTP staff, the design flux rate for the Lopez WTP was 55 gallons-per-square-foot (of membrane area) per-day (gfd). Furthermore, the plant production is limited by permit to less than 7 MGD.

The design production for the Lopez WTP is 6 MGD. The average recovery of the MF system is 94 percent, so the Lopez WTP MF system must operate at an average of 6.4 MGD to produce 6 MGD of filtered water over a 24 hr period. The Pall design drawings show a maximum system production of 6.8 MGD (4,782 gpm gross production). This additional production could be to account for down time of the MF units for backwashing, EFMC and membrane integrity testing (MIT).

Therefore, assuming a maximum system production of 6.8 MGD to produce 6 MGD over a 24 hr period, Table 1 below shows the calculated flow and flux rate for each skid, depending on the number of skids in operation.

Table 1: MF System Instantaneous Flow and Flux Rates

Number of Skids in Operation	Capacity per skid in gpm to produce 6 MGD, over 24 hrs	Maximum Flux Rate, with 58 modules, gfd
5 skids	949	44
4 skids	1,186	55
3 skids	1,582	73

Note: the instantaneous flow rate is 6.8 MGD to provide an average of 6 MGD over 24 hours

The calculated flux rate of 44 gfd with all five skids in operation and 55 gfd with four skids in operation appears to be reasonable, based on other operating Pall systems, and is within the stated design flux for the project. However, a relatively high flux of over 70 gfd (in a case where only three trains are trying to meet the full capacity) could be contributing to the greater than anticipated fouling of the membrane elements. This is discussed in more detail in Section 4 of this report on potential membrane fouling.

At high plant flowrates, when more than one MF unit is stopped (one is in backwash and one is in EFMC or an integrity test), the current flow control approach may be creating excessive flux rates in the operational MF units. We understand that the Pall system has a flowrate limit of 1,400 gpm on the individual units to help avoid operating with an excessive flux rate.

SLCO PW should also consider programming the SCADA system to reduce the overall plant flowrate setpoint during periods when a MF unit goes into a longer term shutdown (an EFMC or integrity test) so as not to over-flux the remaining operational units.

2.6 Filtrate Flow Control Issues

The filtrate flow from the five MF units at the Lopez WTP is highly variable as the MF units start and stop. This is the nature of a membrane plant. This variability is impacting the ability to reliably feed chlorine (sodium hypochlorite) and ammonia to the filtered water. The chemical addition and filtrate flow control issues at the Lopez WTP are made more difficult by the following additional factors:

- There is no combined filtrate flow meter.
- MF Filtrate flow is calculated from the sum of the individual MF influent flow meters. These flow meters measure multiple flow paths through the MF unit at different times during the MF system operation. The PLC must correctly know when to use the MF influent flow meter information to calculate the filtrate flow and when to exclude it.
- The MF backwash water is taken from the filtered water header before chemical addition and this flow rate may not be accounted for in the calculated net filtrate flow rate. The SCADA system should be programmed to subtract the backwash flow rate from the calculated flow rate when the backwash pump is operating.

- Air is being drawn into the filtered water pipeline due to the system hydraulic conditions (see Section 7 of this report).

- The filtrate water quality sampling station downstream of the MF system gets air-bound and is not in operation.

- The chemical feed control is flow paced only. There is no residual feedback for the chlorine or ammonia to help dampen the impacts from the flow variability. Incorporating feedback data from chlorine residual analyzers in a compound loop control would provide benefits for chemical feed control.

2.7 Recommendations

To improve the filtered water chlorine feed control, Kennedy/Jenks recommends adding residual feedback control to work in a compound loop with the flow pacing of the chemical feed pumps. Compound loop control provides the following benefits:

1. Provides better control of actual residual in water stream and thus optimizes the use of chemicals.

2. Provides faster reaction to changes in flow or residual.

3. Provides more flexibility to the operator to select the proper controls to match plant's needs.

In the compound loop mode, the operator selects the desired chlorine residual. The PLC/SCADA would compare the setpoint to the actual residual and adjusts the hypochlorite feed up or down. In addition, the control loop uses the flow signal to compute the required feed rate of hypochlorite to meet the dosage requirement for flow changes.

The operator would still have the flexibility to select the flow pacing only option, where the PLC just computes the required feed rate of hypochlorite to meet the dosage setpoint, as is currently done. This mode is an open loop that does not use the residual analyzer to correct for variations in actual residual. To help stabilize the flow signal which fluctuates rapidly during backwash and integrity tests, a timed average of the flow signal (adjustable from 1 to 10 min) could also be introduced into the PLC programming. The overall system would still be self correcting based on the desired residual setpoint.

To successfully implement this residual feedback control approach, additional issues must be addressed. These include:

- Move the chlorine addition point to upstream of the sample location for Water Quality Station 7. Recommend an injection nozzle high on the 20-inch filtered water pipeline just before the 90-degree bend in the pipeline. The chemical injection quill should extend approximately 1/3 way into the flow of the pipe.

- Provide appropriate rapid mixing of hypochlorite chemical into the process stream. Kennedy/Jenks recommends a wafer-style static mixer with integral chemical injection port. This type of static mixer is not prone to plugging when high pH chemicals, such as hypochlorite, are added to hard water that precipitate scale. Another option could be to install to locate the injection point before some pipe features that produce significant turbulence.

- Address the filtered water hydraulics issues (See Section 7) and locate the sample tap for Water Quality Station 7 so that it does not become air-bound. The sample tap should be a quill that extends into the process pipe approximately one-third of the pipe diameter. This helps to ensure that a representative sample is collected and also helps minimize air binding of the sample line. Provide a sample pump to ensure water gets to the analyzers.

- Use the chlorine residual from Water Quality Station 7 to provide compound loop control to maintain the chlorine residual entering the pipeline contactor.

- Consider adding a filtered water flow meter on the exposed filtered water piping after the pipeline contactor. (See Section 7).

- Use the chlorine residual following the chlorine contactor to provide compound loop control for the ammonia addition based on a ratio to the chlorine. Typically this is controlled at a 4 to 1 or 5 to 1, chlorine to ammonia ratio.

Section 3: Scaling Issues

3.1 Background

The surface water from Lopez Reservoir has naturally high hardness and alkalinity. This has led to the deposition of calcium carbonate scale on the membrane feed strainers and the membrane filter elements. This scale buildup is fouling the strainers and membranes and requires excessive system maintenance and cost. The strainers must be removed approximately every 6 months for acid cleaning. The MF membranes require additional cleaning using citric acid and this is also causing problems with the disposal of the neutralized citric acid waste.

Based on average water quality data from July 2007 to Dec 2007, the Lopez WTP source water quality is summarized in Table 2 below.

Table 2: Lopez WTP Source Water Characteristics

Water Characteristic	Average Source Water	Typical Scale/Corrosion Control Objectives
pH	8.5	7.5 to 7.8
Hardness, mg/l as CaCO3	350	~120 – 150 or less
Alkalinity, mg/l as CaCO3	250	~100 – 120 or less
Temp, degrees C	20	--
Langlier Saturation Index,	+1.6	-0.5 to +0.5
Calcium Carbonate Precipitation Potential	66	10 to 30
Ryznar Index	5.3	6 to 8
Aggressive Index	13.4	> 12

3.2 Scaling and Corrosion Control

There are a number of indices and characteristics that relate to the probable scaling and corrosion potential of various minerals in water including the Langelier Saturation Index, Ryznar Index, Aggressive Index and Larson Index. An explanation of what these indices mean and reference to corrosion of a particular material is described below:

Langelier Saturation Index (LSI) – This is an index of calcium carbonate saturation developed nearly 70 years ago by Dr. Wilfred Langelier, Professor of Sanitary Chemistry at the University of California, Berkeley.

The Langelier Index is calculated as LSI = pH - pH_S. The pH_S of calcium carbonate saturation is calculated from TDS, temperature, calcium, and bicarbonate concentrations:

pH_S = Temperature + TDS – Calcium – Alkalinity Factors

Temperature, calcium, and alkalinity have major effects, while TDS has a minor effect on pH_S. As pH, hardness and alkalinity rise, there is a tendency for calcium carbonate scale to form. Also, if TDS, calcium, and alkalinity are constant, as temperature rises, calcium carbonate will precipitate at lower pH, a condition observed with high hardness hot water in dishwashers, glasses, etc. (Singley, 1985).

Cement and concrete are largely composed of calcium carbonate. At negative Langelier Indices, there is a tendency for the calcium and carbonate to leach out from the cement, leaving a weak matrix of aluminum and silicate as well as roughened surfaces, which increases friction and low flow capacity in pipelines (Holtschulte, 1985). While at positive Langelier Indices, there is a tendency to form calcium carbonate scales, which provides some protection of metals from corrosion, but if too high then excessive and roughed films will form, pipe diameter will be reduced and also result in flow loss (Ryder, 1985).

The most desirable range of LSI is between –0.5 and +0.5, where neither scale deposition nor calcium leaching is excessive (Vik, 1996). A slightly positive LSI of approximately 0.5 is desirable to form a thin protective scale on distribution pipes to minimize corrosion.

The calcium precipitation potential is an index related to the estimated rate of precipitation of calcium scale. The rate of scale formation is related to the square in the change of the calcium precipitation potential index number. So, by reducing the calcium precipitation potential by half, the rate of scale formation would decrease by a factor of four.

The Lopez WTP source water has a LSI of 1.6 which tends to precipitate scale.

Calcium Carbonate Precipitation Potential (CCPP)

The term Calcium Carbonate Precipitation Potential (CCPP) is a term developed by D.T. Merrill and R.L. Schultz at the University of Colorado in 1977, to denote the quantity of $CaCO_3$ that can theoretically be precipitated from over saturated waters or dissolved in under saturated waters.

CCPP = 50,000 (AIk; - Alk_{eq})

AIk_i = Initial Alkalinity

AIk_{eq} = Calcium and Alkalinity after precipitation.

The CCPP predicts the theoretical maximum amount of calcium carbonate that may be precipitated, based upon temperature, pressure, pH, total dissolved solids, and solids, and kinetic equilibrium concentrations. However, it is not an accurate predictor of calcite scale that forms and adheres to the surface. It is likely that some of the calcium carbonate precipitates are the minerals valerite or aragonite that form tiny colloidal precipitates in the water, but are not as adherent as calcite.

The rate of precipitation is a function of the square of the CCPP concentration. Thus a reduction of the CCPP by half will lower the precipitation rate to one quarter, and a reduction of CCPP to ten percent will reduce the precipitation rate to one percent.

The Lopez WTP source water has a CCPP of approximately 66 which tends to precipitate scale.

The recommendation of a CCPP in the 4 to 10 mg/l range is a useful parameter for corrosion protection, but often is too low for calcite scale control. A CCPP in the rage of 10 to 30 mg/l should be acceptable to reduce scale precipitation and also provide for a thin protective scale for corrosion control.

Ryznar Index (RI) - This index is derived from the formula RI = 2 pH_S – pH, and was developed from the Langelier Index by Dr. Ryznar, a chemist with Nalco Water Conditioning Company of Illinois, empirically by observations of steel pipe corrosion (EES-K/J 1989). A relatively benign condition occurs in the R.I. range of 6 to 8, however, above 8, corrosion of steel or cast/ductile iron occurs more rapidly and increased metal leaching and aggravated corrosion occurs, while below 6 – scale formation is prevalent (Singley 1985).

The Lopez WTP source water has a RI of 5.3 which tends to precipitate scale.

Aggressive Index (A.I.) - This index was originally developed by the AWWA Standards Committee for Asbestos Cement Pipe as a simplified calcium carbonate saturation degree measurement, considering only the water pH, calcium and alkalinity concentration, while neglecting the relatively minor effects of TDS and the relatively low temperature range of water distribution piping. It is computed as:

A.I. = pH + log (Ca x Alk) (expressed as $CaCO_3$)

Above an A.I. of 12 no cement deterioration is expected, while unprotected cement is not recommended when A.I. is less than 10. A.I. ranges between 12 and 10 are increasingly more aggressive, approaching 10 (Singley, 1985).

The Lopez WTP source water has an A.I. of 13.4 which is protective of concrete pipe lining and structures.

3.3 Methods of Scale and Corrosion Control

There are several potential scale control methods, including:

- Acid addition with CO_2, or a mineral acid to reduce pH
- Phosphate inhibitor addition to sequester the calcium carbonate
- Non-chemical, electromagnetic scale control
- Water softening using pellet softeners

It is important in evaluating a scale control approach to also consider the impacts on downstream and distribution system corrosion.

3.3.1 Acid Addition

The membrane manufacturer, Pall Corporation, has recommended acid addition to reduce the pH of the source water and minimize scale formation potential of the water. Pall recommended mineral acid addition to achieve a pH of approximately 7.5 and an LSI of approximately +0.5. These are reasonable scale and corrosion water quality objectives.

Table 3 below shows the impact on the water scale and corrosion characteristics with carbon dioxide and a mineral acid (sulfuric acid) chemical addition. The water characteristics and corrosion indices were calculated using the Rothberg, Tamburini & Winsor (RTW) Model for Corrosion Control and Process Chemistry, version 3.0.

Table 3: Water Characteristics with Acid Addition

Water Characteristic	**pH Reduction with Carbon Dioxide to LSI ~0.5**	**pH Reduction with Carbon Dioxide to LSI ~0**	**pH Reduction with Sulfuric Acid to LSI ~0.5**	**pH Reduction with Sulfuric Acid to LSI ~0**	**Typical Scale/ Corrosion Control Objectives**
Acid dose, mg/l	25	50	25	45	
pH	7.3	7.0	7.3	7.0	7.5 to 7.8
Hardness, mg/l as CaCO3	350	350	350	350	~120 – 150 or less
Alkalinity, mg/l as CaCO3	250	250	250	250	~100 – 120 or less
Temp, degrees C	20	20	20	20	--
Langlier Saturation Index,	+0.4	+0.1	+0.4	+0.02	- 0.5 to +0.5
Calcium Carbonate Precipitation Potential, mg/l	37	12	37	6	10 to 30
Ryznar Index	6.5	6.8	6.6	7	6 to 8
Aggressive Index	12.3	12	12.2	11.8	> 12

While similar doses of carbon dioxide and mineral acid will reduce the LSI to about the same level, there are advantages to using carbon dioxide. Carbon dioxide is a common water treatment chemical and offers the following advantages over mineral acids for potable water pH adjustment:

- Not a hazardous chemical
- Storage and feed equipment can be leased or purchased (liquid CO_2 storage)
- Relatively low chemical cost
- Easier pH control due to interaction with alkalinity
- Reduces the potential for accelerated downstream corrosion as compared to strong anions from mineral acids (sulfates and chlorides)

3.3.1.1 Carbon Dioxide Feed System

Liquid carbon dioxide (CO_2) could be stored on site in horizontal insulated storage units. The horizontal storage systems provide for better aesthetics at the site and are better suited for seismic conditions. The CO_2 storage would provide approximately 30 days of storage at maximum flow conditions.

The liquid CO_2 would be vaporized into a gas and then dissolved into a carrier solution under high pressure to create a carbonic acid feed solution. This approach improves the efficiency of the system and permits the CO_2 to be rapidly mixed into solution a short time and in a pipeline without a large baffled tank.

To add carbon dioxide to the Lopez WTP, the carbon dioxide could be dissolved into a side stream with an adductor system and contact chamber, to create a carbonic acid solution. The carbonic acid solution could be introduced to the process water downstream of the chlorine dioxide contactor-- so as not to impact the effectiveness of the chlorine dioxide (higher disinfection at higher pH) in the membrane feed pump wet well. The carbon dioxide feed rate could be controlled by both the flow rate into the membranes and pH feed back through compound loop control.

Table 4: Carbon Dioxide System Parameters

PROCESS DESCRIPTION	**Unit**	**Avg Flow and Avg Dose**	**Avg Flow and Max Dose**	**Max Flow and Max Dose**
Carbon Dioxide System				
Process Flow	MGD	4.5	4.5	6.7
Design Finished Water pH Range	pH	7.3	7.0	7.0
Design CO_2 Dose	mg/l	25	50	50
Design CO_2 Addition Rate	ppd	940	1,870	2,790
CO_2 Storage and Feeder Units	number	1	1	1
CO_2 Storage Capacity (each)	pounds	100,000	100,000	100,000
Supply at usage rate	days	105	53	35

We received quotes from two suppliers of CO_2: Praxair ($0.09/lb), and Airgas ($0.15/lb). Based on the lower cost of carbon dioxide the cost to reduce the pH for scale control would be approximately $85 per day or $31,000 per year at average flow and dose.

3.3.1.2 Mineral Acid Feed System

Liquid mineral acid, such as sulfuric or hydrochloric acid, could be stored on site in chemical storage tanks. The mineral acid storage would provide approximately 30 days of storage at maximum flow conditions. This evaluation assumes sulfuric acid since it tends to be less costly than hydrochloric acid.

The liquid chemical would be fed to the process water with chemical metering pumps. The acid solution could be introduced to the process water downstream of the chlorine dioxide contactor in the membrane feed pump wet well so as not to impact the effectiveness of the chlorine dioxide (works better at high pH). The acid feed rate could be controlled by both the flow rate into the membranes and pH feed back through compound loop control.

Table 5: Sulfuric Acid System Parameters

PROCESS DESCRIPTION	Unit	Avg Flow and Avg Dose	Avg Flow and Max Dose	Max Flow and Max Dose
Sulfuric Acid System				
Process Flow	MGD	4.5	4.5	6.7
Design Finished Water pH Range	pH	7.3	7.0	7.0
Design H_2SO_4 Dose	mg/l	25	45	45
Design H_2SO_4 Addition Rate	ppd	940	1,690	2,510
Chemical Conc. (at 93%)	lbs/gal	14	14	14
Chemical Usage	gpd	67	121	180
H_2SO_4 Storage Tanks	number	2	2	2
H_2SO_4 Storage Capacity (each)	gallons	3,500	3,500	3,500
H_2SO_4 Storage Capacity (total)	gallons	7,000	7,000	7,000
Supply at usage rate	days	105	57	38

Based on a sulfuric acid cost of $0.08 per pound (cost from Pall letter), the cost to reduce the pH for scale control would be approximately $75 per day or $28,000 per year at average flow and dose.

3.3.2 Scale Inhibitor

The addition of a polyphosphate scale inhibitor or sequesterant to the process water at the Lopez WTP can act to complex the calcium ions and prevent scale from forming. Calgon Corporation and others have produced NSF 60 approved, sodium hexametaphosphate for scale control for over 50 years. The advantage of a sequesterant is that it can provide a relatively simple system for scale control.

The drawback with the scale inhibitor is that to sequester the high hardness levels in the source water, a relatively high dosage of inhibitor is required. Based on a typical rule of thumb, 1 mg/l of inhibitor, as phosphorous (P), is required for every 50 mg/l of hardness. Based on the typical hardness levels for the Lopez WTP, the inhibitor dose would be 7 to 8 mg/l of inhibitor as P or 20 mg/l as phosphate (PO_4).

The scale inhibitor chemicals can also be relatively costly. Based on a cost of $1 per pound of inhibitor, as P, a dose rate of 8 mg/l, and an average plant flow rate of 4.5 MGD, the daily cost would be approximately $300 per day or $110,000 per year.

This is a relatively high dose rate for polyphosphate inhibitor. The use of a polyphosphate inhibitor would need to be confirmed with the membrane supplier to ensure it did not adversely impact the performance of the membranes. The phosphates can also act as a nutrient for nitrification and affect biological growth in the distribution system and potentially generate objectionable tastes and odors. In addition, if too much sequesterant is added, it may soften and remove protective scale deposits and create sites for accelerated anodic pitting in the distribution piping and consumer plumbing systems, leading to increased corrosion. In order to minimize this potential, it may be necessary to use either a blended ortho-polyphosphate and/or add additional corrosion inhibitor downstream of the MF system.

3.3.3 Non-chemical Electromagnetic Scale Control

Physical electro-magnetic treatment for the prevention of scale has been actively used as an alternative to chemical treatment of water for over 50 years. These physical treatment devices include units that use either electric or magnetic fields. They are primarily used for recirculating hot and cold water systems in commercial and industrial enterprises.

Electronic or magnetic water conditioners subject the water to a modulated electromagnetic field which suppresses the formation of calcite crystals and favors the formation of microscopic calcium carbonate, aragonite crystals. The aragonite crystals tend to be free floating and do not readily adhere to the pipe walls. The result is that a percentage of the calcite is substantially reduced from solution and will not precipitate on the pipelines or equipment. The microscopic aragonite crystals will stay in the crystallized form for up to several days following their excitation and formation.

The electronic or magnetic water conditioners typically consist of a control unit and a field coil or magnet. The field coil is an insulated wire that is wrapped around the carriage water pipe to produce the varying frequency in the carriage water stream. The system is small and can be integrated in one box with an inlet and outlet, or set up with a separate control unit and field coil depending on the manufacturer. The electronic water conditioners are sized based on flow rate.

The advantages of this approach are that no additional chemicals are added to the water, there is little extra equipment and little space is required. Three individual electronic or magnetic water conditioner units could be placed around the piping between the membrane feed pumps and the feed strainers.

A disadvantage of this approach is that for single pass systems, the reduction in scale is estimated to only be 25 – to 30 –percent. For recirculation systems the reduction in scale has been shown to be approximately 80-percent. Also, this approach would need to be confirmed with the membrane manufacturer since there are likely few applications of this type ahead of membrane filters. This approach to scale control would need further investigation and pilot testing to more completely evaluate the viability of this approach.

3.3.4 Pellet Softening

Another approach to reduce the scale formation in the Lopez WTP and in the distribution system would be to soften all or a portion of the feed water to reduce the hardness in the water. This provides additional benefits to the community water and wastewater systems, including to:

- Improve the aesthetic water quality of the finished water from lower hardness
- Reduce the need for and cost of home water softeners
- Reduce the salts (from the water supply and from home water softener regeneration) from discharge to the environment
- Reduce scale build-up in the distribution system and domestic appliances
- Lowers the TDS going to the wastewater treatment plant
- Permits easier recycling of wastewater due to lower TDS
- Reduces the potential for downstream corrosion potential as compared to strong anions from mineral acids (sulfates and chlorides).

Pellet softening is a variation of conventional cold lime precipitation of calcium hardness together with alkalinity at elevated pH. The pellet process is a high rate, up-flow suspended media where calcium carbonate forms marble hard granules surrounding fine sand nuclei. When the sand and calcium carbonate form a large particle, the pellets are discharged from the unit and the sand is replaced. The discharge of scaled pellets and replacement of sand is a continuous "feed and bleed" process in the operating pellet softener system. The pellets are disposed of as a solid waste and often used for agricultural land treatment of acidic soils. The softened water is then clarified or filtered to remove excess scale particles.

A significant advantage of pellet softening over conventional softening reactor-clarifiers is reduced process area. Typically, the area required for a pellet softener is 10 to 15 percent that of a lime softening reactor clarifier. Another significant advantage of pellet softening is that the precipitates of calcium and magnesium hardness form a pellet instead of a slurry. The pellets are typically two to three millimeters in diameter and contain about five percent moisture. A conventional softening slurry sludge is typically about 5 percent solids and 95 percent moisture, and more than twenty times the volume of the pellet waste.

Overall, a pellet softener is about 20 feet tall. The initial bed of sand is about 4 feet deep and it is expanded to between 12 and 15 feet during operation. The overflow from a pellet softener has turbidity in the range of 10 NTU. It is necessary to re-carbonate the water with carbon dioxide addition to lower the pH to about 8.0. A residual hardness of about 20 mg/L as calcium hardness and the magnesium non-carbonate (chloride or sulfate) hardness remains in the water.

Pellet softening has been utilized for more than 50 years in industrial water treatment in the United States as developed by the Permutit Company as the "Spiractor" softener, in France by Degremont as the "Gyractor" softener and by Rossmark as the Woerden Reactor in the Netherlands. Procorp Enterprises of Wisconsin has licensed the Dutch reactor and has supplied them in the US in the past few years.

A pellet softening process could treat the full process flow or a portion of the process flow to achieve a target hardness and alkalinity level to minimize scaling. The pellet softening system could be placed up-stream of the DAF process at the Lopez WTP.

Please refer to a Technical Memorandum (TM) titled "Conceptual Design and Opinion of Cost for a Pellet Softener System" for more details on a potential pellet softening system for the Lopez WTP. The TM is provided as an attachment to the report.

3.4 Recommendations

Kennedy/Jenks recommends:

1. Acid addition with CO_2 to minimize the scaling in the Lopez WTP strainers, MF system and ancillary equipment.

2. SLOC PW should consider pellet softening as a long term solution to the scaling issues at the Lopez WTP because of the other water quality benefits from this approach

Section 4: Membrane Fouling and Revised Cleaning Regime

4.1 Background

The Pall membrane filters have experienced greater than anticipated membrane fouling which has required more frequent cleanings than was originally anticipated. Membrane fouling could be related to the following factors and conditions:

Inorganic Fouling

- Natural calcium carbonate scaling from the raw water
- Induced calcium carbonate scaling from the high pH cleaning solutions used to clean the membranes

Organic Fouling

- Organic foulants in the raw water

Membrane Flux Rate

- Possible high operational membrane flux rates may result in a higher fouling rate from inorganic or organic foulants.

The MF membrane skids are being cleaned by a Clean-In-Place (CIP) procedure approximately every month. This is consistent with the original design documents. However, the Lopez WTP staff has had to implement additional enhanced flux maintenance cleanings (EFMC) for the MF system that are greater than anticipated by the original design.

Initially, the MF membrane system required a two-part EFMC that was performed approximately every 24 to 48 hrs. The two part EFMC was a 30 minute feed side recirculation of high pH, 700 ppm chlorine solution (made with hypochlorite), followed by a 30 minute feed side recirculation of low pH, 1 percent citric acid solution. Due to the fouling of the membranes, the daily acid EFMC was required to maintain the system performance. The additional cleaning using citric acid is costly and was also causing problems with the disposal of the neutralized citric acid waste.

As of June 2008, the MF skid EFMC schedule has evolved to conducting a EFMC every 1.7 million gallons of treated water. This is approximately every 24 to 48 hours per skid depending on plant flow rates. The chlorine EFMC is performed for six (6) events and then the acid EFMC is performed on the seventh event. It is our understanding that the original design concept had been to perform only a 1 part hypochlorite EFMC once per day and an acid EFMC perhaps once per week. The current (June 2008) cleaning operation is therefore, close to the original design. However, changes in source water quality or system flowrates could increase cleaning frequency again.

4.2 Fouling from Natural Scale Precipitation

The previous section described the natural tendency of the Lopez WTP source water to precipitate calcium carbonate scale. This scaling is likely contributing to inorganic fouling of the MF membranes. Periodic acid cleaning will be required to dissolve this scale.

Implementing carbon dioxide feed or pellet softening to the MF feed water would help reduce the natural calcium carbonate scaling of the Pall system and minimize the acid CIP and EFM cleanings.

4.3 Fouling from Scale Precipitation during High pH EFMC

High pH cleanings, using sodium hypochlorite or sodium hydroxide, are used to remove organic foulants from the membrane surface. Additional calcium carbonate fouling of the membranes is likely occurring during the high pH, hypochlorite EFMC.

The make up water for the EFMC is filtered water that still contains high levels of hardness and alkalinity. When this water is used to prepare a high pH cleaning solution, the calcium and magnesium hardness in the water will precipitate and produce solids in the cleaning solution. The plant staff has observed these suspended solids in the high pH cleaning solution.

When this cleaning solution with the calcium and magnesium precipitates is circulated through the membrane system, the solids can deposit on the membrane surfaces creating inorganic foulants. An acid cleaning is then required to remove the inorganic foulants from the membrane.

Alternatives to minimize the fouling from scale precipitation due to the high pH EFMC include:

- Softening the high pH EFMC water with a water softener system
- Softening the high pH EFMC water with a package nanofiltration (NF) system
- Possibly filtering the hardness precipitates from the cleaning solution before it is sent to the MF system

4.3.1 Water Softener System

Softening the make-up water for the high pH EFMC and CIP removes almost all of the calcium and magnesium ions. Therefore, calcium and magnesium precipitates do not form to any extreme degree and scaling in the MF system is minimized. Softening can be achieved with an automatic, sensed regeneration, dual softener system that requires little maintenance or operator action. The softener could be installed in the water supply pipeline for the EFMC and caustic CIP tanks. Softening is not required for low pH, acidic EFMC or CIP solutions.

The automatic regenerating softeners typically use sodium chloride to regenerate the ion exchange resin and create a brine stream on regeneration that has relatively high levels of calcium, magnesium, sodium and chloride. This may be difficult to discharge at the Lopez WTP since there is not a sewer connection.

Another option is to use Potassium Chloride salts for regenerating the softeners. The brine stream on regeneration that has relatively high levels of calcium, magnesium, chloride and potassium. The reduced levels of sodium in the brine waste may make the waste easier to discharge since potassium is a more beneficial mineral to soil than sodium.

Offsite regeneration is another option, where a softener system supplier will remove and replace the ion exchange cylinders and regenerate the resin at an offsite facility.

4.3.2 Nanofiltration Softener System

Softening of the makeup water for the EFMC and Caustic CIP tanks could also be done using an automated packaged nanofiltration (NF) system. The NF system removes hardness from the water through a spiral wound membrane process. The NF system could be designed to operate at a relatively low recovery to minimize or eliminate the feed chemicals required and to minimize the concentration of the concentrate stream. Because the NF is not adding to the mass of dissolved minerals to the water, the concentrate stream could be recycled through the plant to minimize waste generation.

The NF softener could be installed in the water supply pipeline for the EFMC and caustic CIP tanks. Softening is not required for low pH, acidic EFMC or CIP solutions.

4.3.3 EFMC Solution Filtering System

Another potential approach to minimizing the hardness precipitates in the cleaning solution could be to install a small transfer pump and duplex cartridge filter system to remove a majority of the suspended hardness precipitates from the cleaning solution before it is sent to the MF system.

The system would need to be manually operated since there is a potential to quickly plug the cartridge filter system while removing the solids. The duplex cartridge filter would permit an operator to replace a cartridge filter on one side while still filtering with the other side. There is the potential to use up a number of filters for each cleaning operation. The EFMC solution could be prepared in the EFMC tank and then filtered as it is transferred to the Caustic CIP tank. The operator could then filter it again by transferring the solution back to the EFMC tank. This would be a labor intensive process.

Kennedy/Jenks recommends further investigation of the ion exchange or NF softener approach to address this issue as opposed to the EFMC filtering approach due to the potential labor effort. Furthermore, the duplex cartridge filters may not remove sufficient hardness precipitates to significantly reduce the number of acid EFMCs required for the MF system.

4.4 Fouling from Organic Materials

From the water quality data for approximately the first six months of operation, the source water total organic carbon (TOC) was moderately high in the range of 5.5 to 6 mg/l. The dissolved organic carbon (DOC) was only slightly less than the TOC. This shows that most of the organics are colloidal particulates less than 0.45 microns in size (the cutoff for the standard suspended solids test).

The measured TOC for the combined influent water is higher than the raw water, in the range of 6 to 9 mg/l with one measured value of 29 mg/l. This increase in influent TOC is probably due to influence from the recycled MF washwater and potentially some residual citric acid from an acid EFMC, in the case of the 29 mg/l TOC value.

The Lopez WTP is dosing approximately 30 to 35 mg/l of Sumachlor, polyaluminum chlorohydrate coagulant to the DAF process. The coagulation and DAF are providing some minor reduction in TOC. After the DAF process, the measured TOC at the MF filter influent averaged 5.4 mg/l. This level of organics going into the MF filters is moderate and could be contributing to MF membrane organic fouling.

Alternatives to reduce potential organic fouling of the membranes include:

- Powdered activated carbon (PAC) addition to the raw water to adsorb a portion of the DOC in the source water.

- Permanganate addition to pre-oxidize immediate oxidant demand and a portion of the DOC. This would reduce downstream oxidant demand and would help with: maintaining the chlorine dioxide residual (see Section 6); reducing disinfection byproducts, and may help to reduce MF organic fouling.

- Treatment of the MF washwater with a clarifier type process to reduce the amount of solids and TOC recycled back into the main treatment process.

4.5 Fouling from Potentially High Membrane Flux Rates

In general, for a given water quality, the higher the flux rate of a membrane system, the more quickly the membrane system will foul and require cleaning. The membrane flux rate is the amount of flow that passes through a unit area of the membrane surface over a period of time. Flux is typically described in units of gallons of water per square foot of membrane area per day (gfd).

The California Department of Public Health (CDPH) limits membrane flux rates based on the proven ability of the membrane system to achieve removal of pathogens. The CDPH maximum flux rate does not mean that the membrane system will operate at that high flux rate with a reasonable cleaning frequency.

The Lopez WTP has five (5) low-pressure MF membrane skids made by Pall Corporation. Each skid has 58 membrane modules and spaces for 6 additional modules. Each membrane module (or element) has 538 ft^2 of exterior membrane surface area (outside-in flow path). With 58 MF modules, each skid has 31,204 ft^2 of membrane area. According to Lopez WTP staff, the design flux rate for the Lopez WTP was 55 gfd. Furthermore, the plant production is limited by permit to less than 7 MGD.

Lopez WTP MF skid. Notice connections for 6 additional elements per skid at lower right.

The design production for the Lopez WTP is 6 MGD. The average recovery of the MF system is 94 percent, so the Lopez WTP MF system must operate at an average of 6.4 MGD to produce 6 MGD of filtered water over a 24 hr period. The Pall design drawings show a maximum system production of 6.8 MGD (4,782 gpm gross production). This additional production could be to account for down time of the MF units for backwashing, EFMC and membrane integrity testing (MIT).

Assuming a maximum system production of 6.8 MGD to produce 6 MGD over a 24 hr period, Table 6 below shows the flow and flux rate for each skid, depending on the number of skids in operation.

Table 6: Calculated Maximum MF System Instantaneous Flux Rates

Number of Skids in Operation	Capacity per skid in gpm to produce 6 MGD, over 24 hrs	Maximum Flux Rate, with 58 modules, gfd	Maximum Flux Rate, with 64 modules, gfd
5 skids	949	44	39
4 skids	1,186	55	49
3 skids	1,582	73	66

Note: the instantaneous flow rate is 6.8 MGD to provide an average of 6 MGD over 24 hours

The calculated instantaneous flux rate of 44 gfd with all five skids in operation appears to be reasonable flux based on other operating Pall systems, and is below the design flux rate of 55 gfd. With four skids operating the plant can meet its production at the design instantaneous flux rate. However, where a flux of 40 to 50 gfd may provide acceptable performance and reasonable cleaning frequency for one water quality, the same flux can have unacceptable performance and excessive cleaning requirements for another water quality.

Also, the practice of ramping up the flow rates of the operating skids when another skid goes into backwash, EFMC or membrane integrity testing (MIT), may contribute to membrane fouling if the flux rates are significantly increased. From plant operations data from November 2007, the plant production ranged from 4.0 to 5.8 MGD with an average plant flow rate of 5.3 MGD. Assuming that the MF filters were operating at higher rates to account for backwash and other down times, Table 7 shows the calculated system flux rates.

Table 7: Calculated MF System Instantaneous Flux Rates for November 2007

Number of Skids in Operation	Capacity per skid in gpm to produce 5.3 MGD in 24 hrs	Calculated Flux Rate, with 58 modules, gfd
5 skids	838	38
4 skids	1048	48
3 skids	1,397	64

The Lopez WTP Membrane System Rack Data Report for the month of November 2007 shows the daily maximum membrane flux rates for each rack or skid. The maximum flux rates range from 60 gfd up to **over 90 gfd**. The flux rates of approximately 60 gfd could be when three skids were ramped up to maintain the plant production flow, however, in our opinion, the flux rates of over 60 gfd and up to 90 gfd are excessive and need to be addressed.

During Kennedy/Jenks' site visit, we discussed these apparently high flux rates with the plant operators and with a representative from Pall, Mr. Lucas Albrecht. Potential causes of the high flux are:

- Initially, the MF skid influent control valve was positioned too far open during unit startup following a backwash or EFMC. The clean membrane would operate at a high flux rate until the control valve could act to properly modulate the influent flow rate. Kennedy/Jenks understands that Plant and Pall staff are working to correct this so that the valve is pre-positioned at an initial position to limit the high flux rates on re-start after a backwash or EFMC.

- The MF skid influent flow meter is used to calculate the membrane filtered water flow (there is no filtered water flow meter on the skid), and therefore, the membrane flux rate. The calculation of the membrane flux may be incorrect for short periods of time when the membrane system transitions from backwashing to filtration. During these times, water is flowing through the flow meter and going to both waste and through the membrane.

Kennedy/Jenks recommends that Pall investigate the apparent high flux rates through the membranes. These reported high fluxes, if correct, could be contributing to more rapid fouling. If the reported flux rates are not correct, Pall should correct the flux calculation program.

Discussions with Lopez WTP staff in June 2008, indicate that pre-positioning of the MF skid influent control valve and programming modifications have helped to address this issue.

4.6 Recommendations

Kennedy/Jenks recommends:

1. Softening of the EFCM and CIP make-up water with a package NF system.

2. Confirm and correct the apparent high flux rates through the membranes.

3. Consider adding the additional six (6) membrane modules to each membrane rack to reduce the flux rate and help reduce the rate of fouling.

4. Acid addition with CO_2 to reduce pH and minimize the natural scaling in the MF system and ancillary equipment.

Section 5: Excessive Spent Cleaning Solutions

5.1 Background

The treatment residuals from the Lopez WTP DAF process are sent to two (2) solids drying beds with under-drains at the Lopez WTP site. The water percolates through the drying beds and is discharged to a water course that connects to the spillway of the Lopez Reservoir. This is the historically permitted practice at the Lopez WTP.

For the new Lopez WTP facility construction, no physical changes were made to the solids drying bed system. Changes to the treatment processes and operations at the Lopez WTP were expected to reduce the overall volume of water being discharged to the historically permitted water course but not appreciably change the water quality. According to Lopez WTP staff since the water discharge from the Lopez WTP was not expected to change appreciably, the Regional Water Quality Control Board (RWQCB) did not change the Lopez WTP discharge permit.

Residuals drying beds at the Lopez WTP.

The design concept for disposal of the MF system spent cleaning solution was to neutralize the cleaning solution and discharge the expected small volume to the solids drying bed system. The neutralized cleaning solution would combine with the larger volumes of DAF residuals and the water would be discharged to the historically permitted water course.

The greater than expected fouling of the MF filters due to the issues described in Section 4 above has generated greater than expected volume of spent cleaning solution. The greater volume of spent cleaning solution has impacted the operations of the residuals drying beds system. The Lopez WTP staff have been able to adjust flows to the water course from the Lopez Reservoir to ensure compliance with their discharge permit. However, a long-term solution to this problem is needed.

Lopez WTP Staff also mentioned that the current residuals drying beds may not be sized adequately to handle the new DAF treatment processes at the Lopez WTP.

5.2 Cleaning Solution Characteristics

Different levels of membrane cleaning are instituted to reduce membrane fouling and recover membrane permeability: backpulse or backwash; enhanced flux maintenance cleans (EFMC); and extended recovery cleans or Clean-in-Place (CIP) operations.

EFMC and CIP cleaning solutions typically consist of:

- Sodium hypochlorite as the primary cleaning solution for organic foulants
- Citric acid to dissolve iron, manganese or calcium carbonate scales

The EFMC and CIP cleaning solution is circulated through an off-line, isolated membrane unit for 30 minutes to several hours. The cleaning solution typically can be reused for cleaning other units before disposal.

Following an EFMC or CIP of all units to be cleaned, the spent cleaning solution is neutralized in the neutralization tank and discharged to the residuals bed system. Three neutralization agents are typically added to the spent cleaning solution to neutralize chemicals used in the membrane cleaning:

- Sodium hydroxide (caustic soda) - to bring the low pH solutions up to a range of 6 to 9 pH units.
- Citric Acid - to bring the high pH solutions down to a range of 6 to 9 pH units.
- Sodium bisulfite - to reduce the chlorine residual value to zero mg/l.

The membrane CIP and EFMC cleaning schedules are discussed in Section 4. Due to the excessive fouling of the membranes, additional EFMC cleanings have been required to maintain the system performance. The neutralized spent cleaning solutions have elevated levels of total dissolved solids (TDS) in the case of the hypochlorite cleaning solution, and elevated TDS and organics in the case of the citric acid cleaning solution. The high levels of organics in the neutralized citric acid cleaning solution have impacted the performance of the residuals bed system.

5.3 Actions taken by Plant Staff

The Lopez WTP staff have taken the following actions to help improve the performance of the residuals drying beds and minimize the impact of the excessive volumes of neutralized spent cleaning solutions. These actions include:

- Some excess volumes of neutralized spent cleaning solutions have been directed to an intermediate basin for storage before discharge to the residuals beds.

Neutralized cleaning solution being stored in the existing reclamation basin

- Some volumes of neutralized spent cleaning solutions have been trucked offsite to a wastewater treatment plant.
- The Lopez WTP staff have been able to adjust flows to the water course from the Lopez Reservoir to ensure compliance with their discharge permit.

5.4 Observations and Recommendations

Kennedy/Jenks' observations on the issue of excessive spent cleaning solutions and the residuals drying beds include:

- Reduction of the calcium carbonate scaling and other fouling issues with the MF system, described in Section 3 and 4, should reduce the need for the extra cleaning and reduce the volume of spent cleaning solution.
- Discharge of the neutralized hypochlorite cleaning solution could be sent to the drying beds and discharge of the neutralized citric acid cleaning solution could be sent to the reclamation basin. This may permit some short-term flexibility in handling the spent solutions until a more permanent solution is devised. The neutralized hypochlorite cleaning solution could be sent to the solids drying beds as was originally envisioned through the 6-inch neutralized CIP line. The extra neutralized citric acid cleaning solution could be sent to the reclamation basin for storage and handling as is currently practiced.
- The chemical used for performing the acid EFMC and CIP could be changed from citric acid to hydrochloric acid. The neutralized hydrochloric acid cleaning solution would not have the high levels of organics that the neutralized citric acid cleaning solution contains. This may permit more flexibility in handling the spent cleaning solutions. PALL successfully used hydrochloric acid for the CIP cleaning that was conducted in

September 2007. Hydrochloric acid is considered more hazardous from an operational standpoint than citric acid, but it is less expensive and just as effective at removing scale from the membranes.

- Refurbishing the existing four solids drying beds and installing under-drains in the fifth drying bed could provide improved performance and greater flexibility and reliability with the new Lopez WTP treatment systems.

Kennedy/Jenks recommends the following actions for improving the situation with the excessive spent cleaning solutions:

- Control scaling in the Lopez WTP through carbon dioxide addition and take other actions to limit MF fouling (See Sections 3 and 4).
- Segregate the neutralized hypochlorite solution from the neutralized citric acid cleaning solution.
- Discuss with PALL and switch to hydrochloric acid for acid cleanings.

Section 6: Chlorine Dioxide Issues

6.1 Background

The typical chemical addition for the new Lopez WTP overall treatment process is listed below. The approximate chemical dose rates are based on chemical usage during the month of November 2007:

- Coagulant (Sumachlor) addition (approximately 30 to 35 mg/l) at the rapid mix station ahead of the DAF system.
- Chlorine Dioxide addition (approximately 1 mg/l) at the inlet of the chlorine dioxide contact basin.
- Sodium Hypochlorite addition (approximately 2 to 3 mg/l) after the MF filters and before the buried pipeline contactor.
- Ammonia addition (approximately 0.5 to 1 mg/l) after the buried pipeline contactor.

Before the new facilities were constructed at the Lopez WTP, chlorine dioxide had been used in a closed pipeline contactor ahead of the plant as an initial source water oxidant. The new Lopez WTP now uses chlorine dioxide in an open contact basin (with added floating covers) ahead of the MF filters as the primary disinfectant to meet the *Giardia* inactivation requirements of the Surface Water Treatment Rule. The chlorine dioxide addition point is currently the first time the source water is oxidized.

Free chlorine is added after the MF filters to provide virus inactivation and some additional *Giardia* inactivation. Ammonia is added to convert the free chlorine to chloramines to help minimize disinfection byproduct formation in the treated water clearwell and distribution system.

The chlorine dioxide does not produce regulated disinfection byproducts the way that free chlorine would. However, chlorine dioxide produces the regulated compounds chlorite and chlorate, and therefore the addition of chlorine dioxide is limited to approximately less than 1.4 mg/l to keep chlorite and chlorate in the treated water below regulatory limits.

The Lopez WTP does have the ability to add permanganate, powdered activated carbon and/or chlorine dioxide to the source water near the terminal reservoir for taste and odor control or pre-oxidation.

6.2 Chlorine Dioxide Residual Control Issues

During plant startup testing, the Lopez WTP staff could not maintain the chlorine dioxide residual at the end of the open chlorine contact basin. The design engineer prepared a letter for SLOC PW, dated July 9, 2007 that described the possible causes of the lower than expected chlorine dioxide residuals. These possible causes include:

- Generator performance

- Poor diffusion and mixing of the chlorine dioxide solution at the contact basin inlet
- High oxidant demand in the source water
- Photo-decomposition from sunlight
- Off-gassing of the chlorine dioxide from the open contact basin
- Poor sample location at the outlet of the contact basin
- Free discharge across a weir at the end of the contactor and possible off-gassing of the chlorine dioxide.

6.3 Actions taken by Plant Staff

The Lopez WTP staff worked with the chlorine dioxide equipment manufacturer and the design engineer and took the following actions to help improve the chlorine dioxide residual at the end of the open chlorine contact basin. These actions include:

- Modified the chlorine dioxide solution feed injector into the contact basin per manufacturer's suggestion. According to Lopez WTP staff, this action does not appear to have significantly increased the effectiveness of the chlorine dioxide injection.
- Performed jar testing of chlorine dioxide decay in open vessels exposed to sunlight vs. closed, dark vessels. Chlorine dioxide residual was lost quickly in the open, exposed vessels.
- Added floating covers to the chlorine contact basin to minimize off-gassing and photo decomposition. According to Lopez WTP staff, this action significantly improved the chlorine dioxide residual at the end of the basin.

Floating covers over the chlorine dioxide contact basin.

- Operated with free chlorine pre-oxidation (approximately 1 mg/l) in the pipeline from the terminal reservoir to the WTP for a short period in the summer months. According to Lopez WTP staff, the DAF process performance improved and there was no measured increase in disinfection byproduct formation in the treated water. It is likely that the chlorine dioxide residual control was also improved during this time.

- Moved the sample location at the end of the chlorine dioxide contact basin to before the hydraulic control weir and a submerged location in the basin. According to Lopez WTP staff, this action improved the chlorine dioxide residual measured at the end of the basin.
- Installed a chlorine dioxide day tank to maintain system feed stability.
- Conducted pilot study of a closed pipeline contactor in parallel with the chlorine dioxide contactor basin (with floating covers). Initial results from the pilot testing have shown that the closed pipeline contactor with a similar contact detention time provides a chlorine dioxide residual that is 0.1 to 0.2 mg/l greater than the chlorine dioxide contactor basin with floating covers.

During Kennedy/Jenks' site visit at the end of January 2008, Lopez WTP staff described the chlorine dioxide system as "just working to provide the disinfection residual needed." However, there is concern that with warmer temperatures and changes in the water quality, the plant may not be able to maintain the needed chlorine dioxide residual through the contact basin.

From discussions with Lopez WTP Staff in June 2008, the plant has started adding free chlorine as a pre-oxidant to the source water ahead of the DAF. This has improved the performance of coagulation and the DAF and helps with odor control. The pre-oxidation also reduces the immediate oxidant demand and is likely helping to maintain the chlorine dioxide residual through the contactor. Lopez WTP staff commented that the chlorine dioxide system seems to be working better with the free-chlorine pre-oxidation, and that there have not been issues with disinfection byproduct formation.

The Lopez WTP has the ability to add potassium permanganate and powdered activated carbon to the source water for taste and odor control. According to Lopez WTP Staff, the plant has been using potassium permanganate and powdered activated carbon this spring to address stubborn tastes and odors in the source water. These chemicals can be problematic from an operations standpoint, but can be useful for periodic application to address challenging water quality conditions.

6.4 Observations and Recommendations

Kennedy/Jenks' observations on the chlorine dioxide system include:

- Chlorine dioxide use at the Lopez WTP changed from a pre-oxidant chemical where residual control was not a concern, to a disinfectant chemical where maintaining a residual is critical.
- Regular addition of a pre-oxidant chemical such as free chlorine to oxidize immediate oxidant demand in the source water would improve the performance of the DAF and should improve the ability to maintain a chlorine dioxide residual through the contact basin. By using a small amount of free chlorine (approximately 1 mg/l) the initial demand is reduced and disinfection byproduct formation is minimized. Free chlorine is the preferred pre-oxidant over potassium permanganate since potassium permanganate is a

weaker pre-oxidant, is more difficult to handle and an over dose can lead to “pink or red water” conditions. As long as the free chlorine pre-oxidant dose is low and the initial demand consumes the free chlorine, the formation of DBPS should not be significant.

- The floating covers have provided a significant benefit and should be maintained over the chlorine contact basin. This is a relatively simple and effective solution to reduce photo-decomposition and off-gassing of the chlorine dioxide. Covering the chlorine dioxide basin with a pool cover or other rigid structure is probably not worth the cost or added complexity, and would likely not provide a significant improvement over the floating covers.

- The construction of a closed pipeline contactor to replace the chlorine dioxide contact basins would be very costly and would provide only minimal benefits over the existing basin with floating covers. The bench testing showed only a 0.1 to 0.2 mg/l increase in chlorine dioxide levels with a closed contactor.

- The hydraulic flow and mixing conditions at the inlet and outlet of the chlorine dioxide contact basin could be improved to provide for more plug flow like conditions and improved performance of the contact basin. WTP staff could collect representative samples of the water from different locations in the chlorine dioxide contact basin to evaluate the mixing and plug-flow characteristics of the chlorine dioxide contact basin. Samples should be taken near the surface, at mid-depth, and near the bottom of the each of the channels. This may be worth further investigation after the more immediate operational issues are resolved.

Kennedy/Jenks recommends the following additional actions for chlorine dioxide residual control:

- Continue to use free chlorine pre-oxidation of the source water on a regular basis.

Section 7: Filtered Water Hydraulics Issues

7.1 Background

Water is pumped through the MF filters and then flows through a buried disinfection pipeline contactor and into the treated water clearwell. The treated water clearwell at the Lopez WTP is a circular, below-grade reservoir with a maximum water surface level of approximately 318 ft. The MF system is above-grade with the filtrate pipeline from the MF system at an elevation of approximately 340 feet.

The MF membranes require a small amount of backpressure (several psi) to operate properly and to provide sufficient net positive suction head for the MF Backwash Pumps that draw water from the filtered water pipeline just downstream of the MF system. To provide this back pressure, a pressure sustaining valve was installed downstream of the MF Filters.

However, due to the system hydraulic conditions between the MF Filters and the Clearwell, vacuum conditions have been created and air is being drawn into the filtered water. The vacuum conditions are created when the system hydraulic grade line drops below the elevation of the physical piping. The vacuum conditions create the potential for contamination of the filtered water and adversely impact the ability to control the chemical feed addition to the filtered water, as discussed in Section 2 above.

7.2 Filtered Water Hydraulic Profile

The hydraulic conditions of a system are controlled by the next free water surface elevation and the headloss through downstream system components. Kennedy/Jenks prepared a basic hydraulic profile from the treated water clearwell back to the MF filtrate discharge piping to evaluate the Lopez WTP filtered water system hydraulics. Kennedy/Jenks used “as-built” sketches provided by Lopez WTP staff to account for changes made to the filtered water system piping during plant construction. The Filtered Water System Hydraulic Profile is shown for the maximum plant flow rate of 6.7 MGD. The Filtered Water System Hydraulic Profile is included in Appendix B.

The Filtered Water System Hydraulic Profile shows the following:

- There is a hydraulic drop (hydraulic gradeline drops below the elevation of the physical piping) at the piping highpoint near the clearwell. This situation results in vacuum conditions in the pipeline and sucking air into the filtered water through a combination air/vacuum valve as the water goes down into the clearwell. The draw of air into the pipe is relatively strong and can easily be felt by the human hand.

Air is being drawn into the filtered water through the vacuum valve on the left

- There is a hydraulic drop just downstream of the pressure sustaining valve that is creating vacuum conditions and sucking air into the filtered water through a combination air/vacuum valve. The draw of air into the pipe is relatively strong and can easily be felt by the human hand.

Air is being drawn into the filtered water through the vacuum valve on the right

- The hydraulic grade line in the MF filtrate piping is very near the physical pipe elevation. As the filtrate flow rate increases and decreases due to the operation of the MF systems, it is likely that the hydraulic grade line drops below the elevation of the physical piping and can draw air into the piping at this location through a combination air/vacuum valve located above the pipe crown.

Air/vacuum valve on MF filtrate piping

7.3 Filtered Water Hydraulics Impacts

The potential impacts of the hydraulic drops in the filtered water system include:

- Potential for contaminants to be drawn into the filtered water through the air/vacuum relief valves.
- Excessive air in the filtered water chlorine contactor pipeline could displace water volume reducing the available disinfection contact volume (probably a minor impact).
- The pressure sustaining valve may have some lag time to adjust to the changes in the filtered water flow rate due to the starting and stopping of the MF units. Abrupt decreases in the flow rate will tend to create vacuum conditions in the MF filtrate piping that draws in air or prevents air from being properly vented.
- Air in the MF filtrate piping (either being drawn in through the vacuum valve or air from a backwash that is not expelled properly) has caused air binding in the water quality sample lines. This is contributing to the filtered water chemical addition control issues described in Section 2.
- The operation of the pressure control valve may be impacted by the hydraulic drop and vacuum conditions on the downstream side of the valve.
- If a vacuum relief valve fails and high vacuum conditions are created within a pipeline, then pipe damage could occur.

7.4 Additional Filtered Water System Observations

During Kennedy/Jenks site visit, we noted the following additional items with the filtered water system that warrant addressing:

- The open end of the vent pipe on the MF filtrate pipe air/vacuum valve is located in a pipe trench. There is the possibility, that if there is water in the trench that submerged the end of the vent, water could be drawn up into the filtered water piping. Kennedy/Jenks recommends that the Lopez WTP staff cut the vent pipe at least 2-pipe diameters above the top of the pipe trench.
- There is an in-line, crossed-vane-type static mixer on the filtered water piping that is used to mix ammonia into the chlorinated water to create chloramines. The ammonia chemical that is added at the mixer has a high pH and is likely to cause calcium carbonate scale precipitation where it is added to the hard water. Over time, the scale can build up and impair or plug the static mixer. There are alternative type static mixers that are not as prone to plugging that could be installed if the existing static mixer plugs up.

Ammonia injection could be causing calcium carbonate scaling in the static mixer.

7.5 Recommendations

Kennedy/Jenks recommends SLOC PW install a hydraulic control weir with a free water discharge condition at the treated water clearwell. This could consist of a modest, above-grade structure that maintains the hydraulic grade line in the filtered water pipeline above the elevation of the pressure sustaining valve, if not higher.

The hydraulic control structure could be a 48-inch diameter welded steel standpipe supported by a concrete slab on grade. The standpipe would be approximately 20-feet tall and would serve to raise the hydraulic grade line, under all plant flow conditions, to above the physical elevation

of the back-pressure sustaining valve. The structure would be built near the current high point in the piping going to the clearwell. The existing 20-inch piping would rise up and connect to the standpipe near the top. The water would freefall in the standpipe and an outlet would connect to the existing piping going into the clearwell.
This would eliminate the vacuum and air entrainment conditions at the clearwell and at the pressure sustaining valve. It may also permit the pressure sustaining valve to perform better and reduce or eliminate air entrainment at the MF filtrate piping.

Kennedy/Jenks recommends that the SLOC PW also consider installing a filtered water flow meter at the location of the current cross-vane-type static mixer and installing an alternative type static mixer that is less vulnerable to plugging, downstream of the proposed flow meter.

Appendix A

Example Control Strategies

CONTROL STRATEGY 3.1

TITLE: Source Water Pump Station and Automatic Screens

AREA: Source Water Pump Station **SHEET**: I-3.1 **PLC**: 1

LOOP NUMBER: 321, 322

RELATED EQUIPMENT: Source Water Pumps (SWP-1, 2, 3)
Membrane Flow Demand, FY-334
Screens No. 1 and 2 (ASM-1, 2)
Sample Pump (SP-314)

A. General: The Source Water Pump Station consists of three pumps each rated at approximately 8 MGD (~5,600 GPM). The pumps are variable speed and operate in conjunction with a modulating membrane basin inlet control valve to fill the membrane basins and maintain level in the membrane basins during operation. Pump Station flow rate is dependent upon the demand (operator selected) and the operating condition of the membranes –number of filters on-line, number in backwash, basins in fill mode, etc. This strategy describes the operation of the Source Water Pump Pumps and Automatic Screens. The Membrane System Supplier (Zenon) shall provide a flow "demand" signal (from PLC 6) for control of the Source Water Pump speed. The Source Water Pumps provide feed water to the membrane filter basins in the Membrane Building.

General: There are two Automatic Screens consisting of a motorized screen and a wash and drain valve to filter water from Kingston Reservoir before it enters the membrane basins. The screens periodically perform an automatic backwash using plant water system pressure to facilitate the wash.

B. MONITORING: Display the following parameters.

1. Pressure: PI-321, 322, 323, 325
2. Flow: FI-326
   Totalizer: FQI-326 (obtain pulse conversion from the meter mfr.)
   Demand: FY-327
3. Analyzers: AI-312, 313, 314, 328
4. Temperature: TI-311
5. Differential Pressure: PDI-330
6. Pump Status:
   Remote; YI-321, 322, 323, 314
   Run; XI-321, 322, 323, 314
   Speed; SI-321, 322, 323
   Run Time; KQ-321, 322, 323, 314
7. Screen Status:
   Valve-Motor Ready; YI-331, 341; YI-332, 342
   Open; ZLO-331, 341, 332, 342
   Closed; ZLC-331, 341, 332, 342
   Fail; UA-331, 341, 332, 342

Backwash-Ready; NI-334
Timer Status; KIQ-334

C. SOURCE WATER PUMP STATION CONTROL:

Note: All drives receive their commands via DeviceNet communications. CP-1 (PLC#1) receives its flow "demand" signal via Ethernet peer-to-peer communications from CP-6 (PLC#6).

1. Manual (HS-321, 322, 323 in REMOTE): The pumps start, if not failed, UA- 321, 322, 323, when placed in HAND at the SCADA Display. Speed control (HC-321, 322, 323) provides manual adjustment of pump speed (0-100%).

2. Automatic (HS-321, 322, 323 in REMOTE): HS-320 selects the LEAD pump. The third pump acting as a standby should one of the other two pumps fail. Provide for pump alternation. Refer to Table 3.1 for pump sequencing.

Table 3.1

Expected Flow Range	Pump Sequencing
0 – 2800 GPM	SWP-1 ON (LEAD) (1) SWP-2 OFF (1)
> 2800 GPM	SWP-1 ON (LEAD) SWP-2 ON (LAG) (2)

Notes:

(1) Each pump shall be calibrated 440 –880 RPM = 30-60 Hz (50-100% speed).

(2) At a flow demand signal, FY-327, equal to or below 2800 GPM (adjustable), the pump speed controller, FC-327, will output a speed signal that is proportional to demand or minimum speed, whichever is greater. At a demand flow signal that is greater than 2800 GPM, the LAG pump starts and ramps to ½ the demand speed. Note: The average flow per basin is 1974 GPM; during rapid fill of a basin the flow to the basin increases temporarily to 7262 GPM.

(3) For flows between 1000 – 11,000 GPM the minimum speed (Hz) shall be increased 3 Hz for every 1000 GPM.

D. AUTOMATIC SCREEN CONTROL:

1. Manual Backwash (HS-334 in HAND): The screen motor energizes and FV-33X/34X open for the recycle timer, KKQ-334, if Screen Backwash Status, NI-334 is READY.

2. Automatic Backwash (HS-334 in RECYCLE-AUTO): The screen motor and FV-33X/34X open on recycle timer, KKQ-334, if Screen Backwash Status, NI-334 is READY. The Recycle Timer, KKQ-334, is operator adjustable to 60 minute each 96 hours (initially set to 10 min each 24 hours).

3. Automatic Backwash (HS-334 in DIFF-AUTO): The screen motor energizes and FV-33X/34X open if Screen Backwash Status, NI-334 is READY and differential pressure, DPSH-330, is high. The Screen continues to backwash until the differential

pressure drops below 3 PSID, adjustable, and continues to run for an additional 30 minutes, adjustable.

4. On completion of the timing cycle or differential pressure controlled wash, the Wash and Drain valves, FV-33X/34X close and Screen motor de-energizes.

E. SAMPLE PUMP, SP-314, CONTROL

1. Manual (HS-314 in REMOTE): Pump starts (HS-314) if not failed (UA-314).
2. Automatic: None.

F. Calculation of CT Required: Compute and display (NI-315AA) the CT value as follows:
Source: EPA Guidance Manual for Regression Method of determining CT Required:

$$\text{CT Required} = (0.353 * I)\left(12.006 + e^{(2.46-0.073*temp+0.125*C+0.389*pH)}\right) \text{(for temperature < 12.5°C)}$$

$$\text{CT Required} = (0.361 * I)\left(-2.261 + e^{(2.69-0.065*temp+0.111*C+0.361*pH)}\right) \text{(for temperature ≥ 12.5°C)}$$

where

I = 0.5 (for 0.5 log reduction)
temp (°C) = TI-311,
C (mg/L) = AI-314,
pH = AI-312

G. Calculation of CT Actual: Compute and display (NI-315B) the CT value as follows:

$$CT|_{Actual} = \left[K_1\left(\frac{LIT\text{-}205 * \text{gal}/\text{ft}}{FI-326}\right)\right] * AI-314$$

Where,
Total Volume is based on the operating level in each reservoir section, LIT-205 (20 FT/10 MG).
Total Flow is based on the actual power reservoir distribution flow, FI-326.
K_1 is a constant, initially set to 0.6 (adjustable) to yield an actual value 40% lower than actual to provide a margin of error for CT compliance.

H. SETPOINTS ACCESSIBLE TO THE OPERATOR:

1. All setpoints
2. All recycle timer and delay timers.
3. All trend variables.

I. ALARMS AND STATUS:

1. UA- 321, 322, 323,314: Alarm activates on drive failure or call-to- run failure.
2. NI-334: Remote status is activated if motor is not running and valves are closed, ZLC-33X/34X.

END OF CS-3.1

CONTROL STRATEGY 4.1

TITLE: Membrane Filter Control

AREA: Membrane Building **SHEET**: I-4.1 and Zenon P&IDs **PLC:** 6

LOOP NUMBER:

RELATED EQUIPMENT: Source Water Pumps, Spent Washwater Pumps, Blowers, Backpulse Pumps, CIP System

A. General: This strategy describes, in general, the operation of the Membrane Filters and associated equipment. The Membrane System Supplier (Zenon) shall provide the PLC Programming and SCADA Screen development for the operation of the Membrane Filters and associated equipment including the permeate pumps, vacuum pumps, backpulse pumps, blowers, compressors, and cleaning systems. The Contractor integrates the Zenon supplied programming into the Plant SCADA system. The following is provided for information only.

B. Description:

1. The Avenue WTP will have seven membrane basins. Initially four basins will have membrane filtration equipment installed to provide 10 MGD of treated water production with no redundant basin. With membrane filtration equipment installed in all seven basins, the plant production will be 15 MGD with one redundant basin to permit maintaining capacity during maintenance or cleaning of a basin. Each membrane basin has a production capacity of 2.5 MGD.
2. The membrane filters will be started manually from the SCADA Screen and then operate automatically to maintain an Operator adjustable production flow setpoint. The Operator can set the flow rate for an individual basin or can set an overall plant production rate that would be met by dividing the production rate by the operating basins.
3. Each membrane basin has a dedicated permeate pump that draws water through the membrane fibers and pumps the filtered water to Power Reservoir. The permeate pumps are variable speed and are controlled by individual basin filtered water flow meters. Vacuum pumps assist the permeate pumps by removing air from the pump suction headers.
4. The membrane filters operate in a constant rate mode, with membrane inlet control valves providing the primary means of flow distribution among the filters. The membrane system controls the number and speed of the Source Water Pumps along with the position of the inlet flow control valve to maintain a minimum level of water above the submerged membrane modules. As the surface of the membrane becomes fouled and the transmembrane pressure (TMP) rises and the variable speed permeate pumps will speed up to maintain a constant flow rate through the filter. If water level in the membrane basins is above or below the level setpoint and the flowrate is at the production rate setpoint, then flow from the source water pumps is adjusted to maintain water level in the membrane basins.

5. Membrane filters can be manually stopped by the Operator from the SCADA Screen or will automatically stop based on an Operator adjustable high level in Power Reservoir.

6. Backpulse (Backwash): Approximately every 60 minutes, the membrane filter will stop filtration and backwash the accumulated solids from the system. During a membrane filter backbulse, the filter inlet valve closes and the permeate pump continues to operate to lower the level in the membrane filter basin to just above the level of the membrane fibers. The duty air blower operates to provide air scour for a period of one to two minutes and then the duty backpulse pump pumps filtered water back through the membrane fiber. The spent backwash water is drained from the basin to the spent washwater sump.

   Filter backpulse can be initiated by the Operator from the SCADA Screen or automatically by the PLC based on process conditions. A filter backpulse would typically be automatically initiated by one of the following process conditions:

   a) Excess Filter TMP: When TMP across the membrane filter exceeds a setpoint, the wash sequence is initiated or put in a cue for backwashing. A LCD notification is displayed.

   b) Time: The membrane filters backpulse regularly based on an Operator adjustable time setpoint.

   c) As part of Maintenance and Recovery (CIP) cleaning.

   The filter backwash steps and controls will be accomplished by the membrane system PLC and viewed from the LCD.

7. Membrane Integrity Monitoring. Membrane integrity monitoring will be provided through both direct and indirect methods. Each membrane basin performs a periodic direct air integrity test, and each membrane basin has a continuous monitoring effluent turbidimeter and particle counter that provides indirect integrity testing. The direct air integrity test would be performed on each membrane basin once every 4 hours for the first several months of system operation and then after DHS approval, once every 24 hours. The combined filtered water will also be monitored with a turbidimeter and particle counter.

8. Membrane Cleaning. The membranes are cleaned by daily Maintenance Cleans using 10 ppm of free chlorine, weekly Maintenance Cleans using 100 ppm of free chlorine and monthly Recovery Cleans using weak chlorine or citric acid solutions. The Maintenance Cleans are fully automated by the Zenon PLC and are monitored by the Operator from the SCADA Screen. The Recovery Cleans are typically initiated by the Operator but then is a fully automated process and can be monitored by the Operator from the SCADA Screen.

END OF CS-4.1

CONTROL STRATEGY 4.3

TITLE: Spent Washwater Pump Operation

AREA: Spent Washwater Pump Station **SHEET**: I-4.2 **PLC**: 7

LOOP NUMBER: HS-402, 403, 404

RELATED EQUIPMENT: WWR Basins, Coagulant System, Membrane Basins

A. General: This control strategy includes the control of three 1500 GPM Spent Washwater Pumps. Spent washwater is gravity drained from the membrane basins to a 20,000 GAL spent washwater sump. The Spent Washwater Pumps are variable speed pumps and operate based on level in the sump to pump the spent washwater to the WWR Basins. Coagulant is added to the spent washwater to help settle the solids in the WWR Basin.

B. MONITORING: Display the following parameters.

1. Pressure: PI-402, 403, 404
2. Flow: FI-405
   Totalizer: FQI-405 (obtain pulse conversion from the meter mfr.)
3. Level: LI-401
4. Pump Status:
   Remote; YI-402, 403, 404
   Run; XI-402, 403, 404
   Speed; SI-402, 403, 404
   Run Time; KQ-402, 403, 404

C. WASHWATER PUMP (SWWP-1/2/3) CONTROL:

Note: All drives receive their commands via DeviceNet communications.

1. Manual (HS-402, 403, 404 in REMOTE): Pumps starts at speed setpoint, HC-402, 403, 404 (adjustable), if not failed, UA-402, 403, 404 or sump level is not low (LAL-401) or low low (LALL-406) when placed in HAND at the SCADA Display. Speed control (HC-402, 403, 404) provides manual adjustment of pump speed (0-100%),

2. Automatic (HS-402, 403, 404 in REMOTE): Pumps starts and speed is adjusted to meet an operator adjustable flow rate setpoint depending on an operator adjustable sump level (See Table 4.1 below), if not failed, UA-402, 403, 404 or sump level is not low (LAL-401) or low low (LALL-406) when placed in AUTO at the SCADA Display. HS-407 selects the LEAD-LAG and STANDBY pumps. The STANDBY pump starts and ramps to speed if a LEAD or LAG pump fails. Provide for pump alternation. Refer to Table 4.1 for pump sequencing.

Table 4.1

Control Level (LY-401)	Pump Sequencing	Flow Control (FY-405A)
0.5 – 2 FT	SWWP-1 ON (LEAD)	350 gpm
> 2 FT – 4 FT	SWWP-1 ON (LEAD)	750 gpm
> 4 FT – 5 FT	SWWP-1 ON (LEAD) (1) SWWP-2 ON (LAG)	1,500 gpm
> 5 FT	SWWP-1 ON (LEAD) (1) SWWP-2 ON (LAG)	2,500 gpm
LSLL-406=0.3 FT. LAL-401=0.5 FT, decreasing.	All Stop	

Notes:
(1) When the lag pump starts, operate both lead and lag pumps at the same speed to meet the flow setpoint.
(2) LAG pumps stop at 3.0 FT, adjustable.

E. SETPOINTS ACCESSIBLE TO THE OPERATOR:

1. All setpoints
2. All recycle timer and delay timers.
3. All trend variables.

F. ALARMS AND STATUS:

1. UA-402, 403, 404: Alarm activates on fan overload or call-to- run failure.
2. UA-700: System stop is activated. See CS1.2.
3. UA-701: Activates on malfunction of the UPS.
4. LY-401: speed computer for LEAD and LAG pumps. See Table 4.1.
5. JA-702: activates on loss of power. See CS1.2
6. LAHH-406: activates on high high level for operator action. No adjustment.
7. LAH-401A: activates LEAD call on high level, initially set to >0.5 FT.
8. LAH-401B: activates LAG call on high level, initially set to >4 FT.
9. LALL-406: alarm activates and all pumps stop. No adjustment .
10. LAL-401: activates to stop all pumps, initially set to 0.5 FT, adjustable.
11. FY-405B: converts the magmeter pulses to equivalent totalized values. See CS1.1.
12. FSH-405: activates to start a coagulant pump when flow exceeds 2% of range (adjustable).

END OF CS-4.3

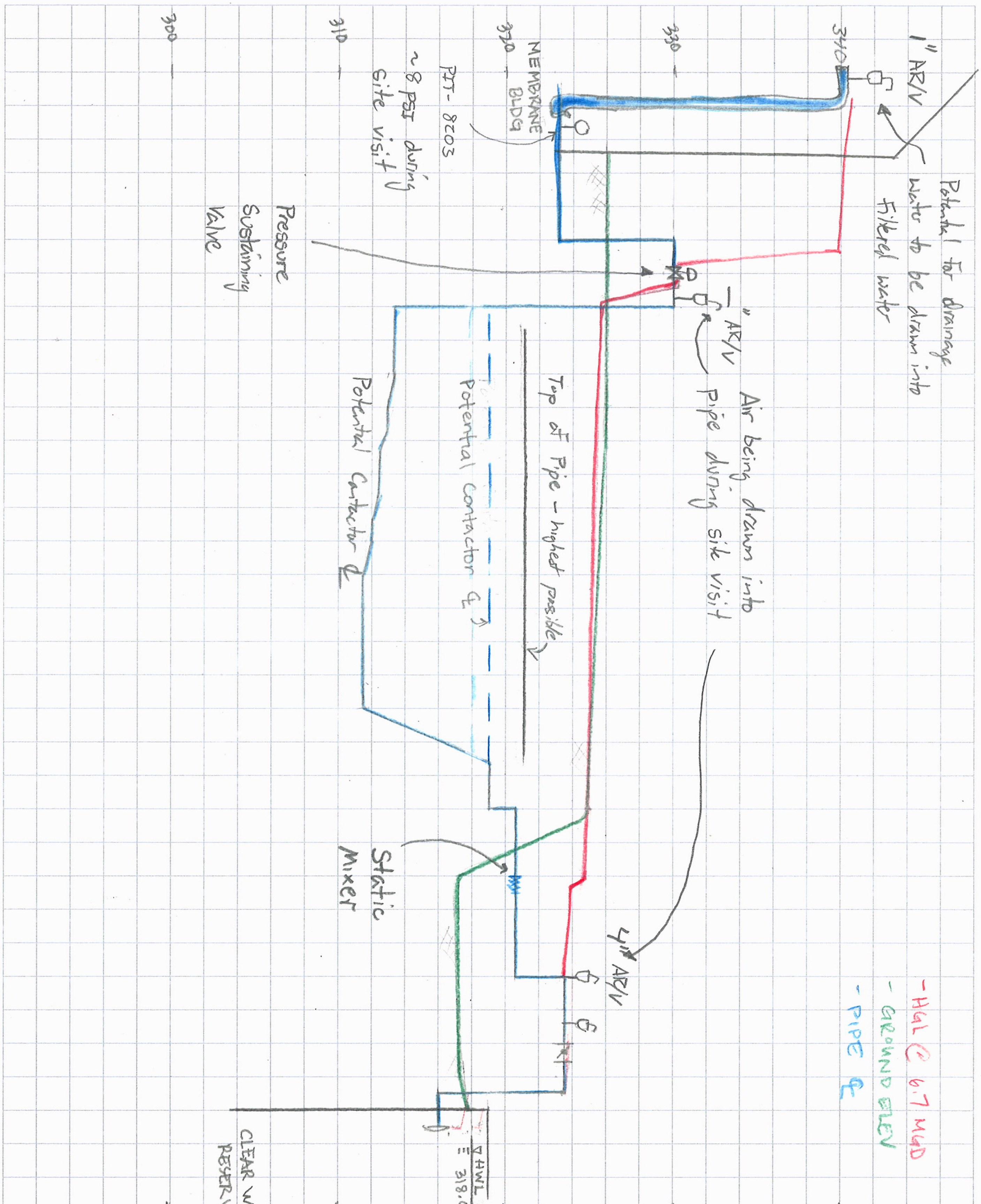
Appendix B

Filtered Water Hydraulic Profile

By Date Job # 0868001

Checked by Date Project SLO CWD LOPEZ WTP EVAL

Subject HYDRAULIC PROFILE - MEMBRANE BLDG TO CLEAR WATER RESERVOIR Sheet of



Appendix C

Conceptual Design and Opinion of Cost for a Pellet Softening System

17 June 2008

Technical Memorandum

To: Mr. Dean Benedix, San Luis Obispo County Public Works

From: Todd Reynolds, P.E., BCEE

Subject: Conceptual Design and Opinion of Cost for a Pellet Softening System
Lopez WTP Evaluation Report
K/J 0868001

Background

In the *Lopez Water Treatment Plant Draft Evaluation Report* (20 March 2008), Kennedy/Jenks provided an evaluation of and recommendations to address operational issues experienced at the Lopez Water Treatment Plant (WTP). One of these issues is scale buildup on the membrane feed strainers and membrane filter elements due to high hardness and alkalinity of the source water. Proposed methods for scale control included:

- Acid addition with CO2, or a mineral acid to reduce pH
- Phosphate inhibitor addition to sequester the calcium carbonate
- Non-chemical, electromagnetic scale control
- Water softening using pellet softeners

Kennedy/Jenks recommended acid addition with CO_2 to minimize the scaling in the Lopez WTP strainers, MF system and ancillary equipment and consideration of pellet softening to provide a long term solution to the scaling issues as well as other water quality benefits.

The San Luis Obispo County Public Works (SLOC PW) has expressed interest in the pellet softening option and has requested Kennedy/Jenks to further develop this option. The purpose of this technical memorandum is to provide a conceptual level design and conceptual opinion of probable capital and operating costs for a pellet softening system at the Lopez WTP.

System Description

Pellet softening has been used for more than fifty years in industrial water treatment in the United States. It is a variation of conventional cold lime precipitation of calcium hardness together with alkalinity at elevated pH. In the pellet softening process, source water flows up through a suspended bed of fine sand. Lime or caustic soda (sodium hydroxide) is added to raise the pH for calcium carbonate crystallization onto the fine sand, producing gravel size pellets. When the sand and calcium carbonate form a large particle, the pellets are discharged from the unit and the sand is replaced. The discharge of scaled pellets and replacement of sand is a continuous “feed and bleed” process in the operating pellet softener system. The pellets are disposed of as a solid waste and often used for agricultural land treatment of acidic soils.

The pellet softening process elevates the pH of the water, and it is necessary to re-carbonate the water with carbon dioxide addition to lower the pH to about 8.0. In some cases, filtration equipment is added downstream of the pellet reactors to remove solids carry-over from the reactor effluent.

Design Criteria

Only a portion of the source water would be treated with the pellet softener, and the softened water would be blended with the source water to achieve the targeted water quality. Based on the source and softened water quality, an approximate blend of two-thirds (2/3) softened water and one-third (1/3) source water is suggested to achieve the target reduction in calcium hardness. Table 1 below shows the water characteristics of the source, softened and blended water. Scaling and corrosion indices for the source and blended water are also included in Table. The index values for the blended water assume pH reduction of the blended water to 8.0.

Table 1: Water Characteristics

Water Characteristic	Units	Source	Softened	Blended[(a)]	Targeted
TDS	mg/L	473	310	364	
pH	pH units	8.2	8.8	8.0	
Calcium Hardness	mg/L as $CaCO_3$	197	28	84	<90 [(g)]
Magnesium Hardness	mg/L as $CaCO_3$	157	157	157	
Total Hardness	mg/L as $CaCO_3$	354	184	240	
Total Alkalinity	mg/L as $CaCO_3$	277	112	166	100-120
Indices[(b)]					
LSI[(c)]		1.6		0.3	-0.5 - +0.5
CCPP[(d)]		66		6.3	10 - 30
RI[(e)]		5.3		7.4	6 - 8
AI[(f)]		13.4		12.1	>12

Notes:

(a) Blended water quality is based on a blend of 2/3 softened water and 1/3 source water.
(b) Calculated using the Rothberg, Tamurini & Winsor (RTW) Model for Corrosion Control and Process Chemistry, version 3.0. Index values for the blended water assume pH reduction of the blended water to 8.0.
(c) Lagalier Saturation Index – Indicator of scale deposition (+) or calcium and carbonate leaching (-).
(d) Calcium Carbonate Precipitation Potential – Indicator of rate of precipitation of calcium scale.
(e) Ryznar Index – Indicator of steel or cast/ductile iron corrosion and metal leaching or scale formation.
(f) Aggressive Index – Indicator of cement deterioration.
(g) The calcium hardness contributes to scaling.

Design criteria for a pellet softening system are given in Table 2 below. Based on a maximum plant flow of 6.7 MGD and softening of only two-thirds (2/3) of the plant flow, two softener units would be provided to treat 4.5 MGD (= 2/3 x 6.7 MGD) of source water, each sized for a flow of 2.25 MGD. Lime or sodium hydroxide can be used to facilitate crystallization of calcium carbonate on the sand nuclei in the pellet reactors.

A sodium hydroxide system is considered for this conceptual design as it is easier to handle, is less labor intensive, requires less equipment and produces a smaller volume of pellets. However, it should be noted that sodium hydroxide has a higher chemical cost, requires greater safety precautions and increases the sodium in the water. The sodium hydroxide and carbonic acid system design criteria are given in Table 2. The chemical dosages were estimated based on typical plant water quality data. Pilot testing is recommended to determine actual chemical dose requirements and to evaluate hardness removal efficiency.

Table 2: Pellet Softener Design Criteria

Item	Units	
Design Flow	MGD	4.5
Approximate Area Required	sq. ft.	6,000
Pellet Softener		
Quantity	number	2
Diameter	feet	8
Height	feet	25
Sand Use	pounds/day	630
Pellet Production	pounds/day (max)	6,300
Pellet Volume	cu. yd./day (max)	3.15
Pellet Disposal	cu. yd./year	1150
Sodium Hydroxide (NaOH)		
NaOH Dose	mg/L	70
NaOH Feed Rate	lb/day	2,610
NaOH Storage	gallons	8,000
Carbon Dioxide		
Recarbonated Water pH	pH units	8.0±
CO_2 Dose	mg/L	50
CO_2 Feed Rate	lb/day	2,800

Equipment and Facility Requirements

The basic equipment required for a Pellet Softening Facility includes a pump station, softening process equipment and ancillary facilities and chemical feed equipment. Filtration or clarification equipment may be added to remove solids carry-over from the reactor effluent. These components are described in the following sections.

Source Water Pump Station

Source water currently gravity flows from the Lopez Reservoir through the Intake Meter Vault and Flash Mixing System to the Dissolved Aeration Floatation (DAF) Tanks. The water flows from the DAF Tanks through the Chlorine Dioxide Contact Basins and is then pumped to the Membrane Filters. The water levels in the reservoir provide sufficient driving head through the pretreatment and chlorine dioxide disinfection systems without the need for pumps.

The pellet softeners would go upstream of the Intake Meter Vault. The softener towers are 25 feet tall and require an inlet pressure of approximately 93 feet to provide mixing energy and to lift the water. Pumps would be required to deliver the source water through the pellet softener. The water level in the reservoir can provide part of the driving head through the pellet reactor, and the pumps would supply the rest. The pumps can be hard piped to the raw water line and would be situated on a pump pad near the pellet reactors. Two pumps would be provided for redundancy.

Softening Process Equipment and Facilities

Two pellet reactors would be provided to treat approximately 4.5 MGD flow. Source water is delivered into the reactor through nozzles located at or near the bottom of the reactor. Chemical reagent (sodium hydroxide) is injected into the reactor through lances designed to provide sufficient mixing energy and dosing. The reactor has an inlet for sand addition, and a feed skid can be provided to automate the loading of the sand into the reactor. The feed skid consists of a hopper into which the sand is unloaded, and the sand is pneumatically transferred into the reactor on a periodic basis to replace discharged media. The pellets are removed from the reactor and emptied into dumpsters through discharge piping with control valves.

Ancillary facilities are needed for electrical and control equipment, sand storage and pellet solids handling and disposal. A small building would be provided for the electrical and control equipment and sand storage. Facilities for pellet disposal include a dumpster pad, three large dumpsters with drain ports, and piping and valves from the pellet softeners to the dumpsters. The pellets would be discharged to the pellet dumpsters on site. The pellets can potentially be reused for agronomic treatment of acidic soils, but if no reuse outlet is found for the pellets, they would be disposed of in a landfill. The dumpsters would be hauled, emptied at the landfill and returned to the plant for refill.

Chemical Feed Equipment

Sodium hydroxide is added to the pellet softening tank to increase pH as necessary to achieve precipitation. Twenty-five percent concentration sodium hydroxide would be used for the chemical feed to the softening process. The sodium hydroxide would be delivered and stored in a chemical storage tank. Feed pumps would be used to deliver the sodium hydroxide to the pellet softener.

Carbon dioxide would be added to the softened water after it exits the reactor for pH reduction. The carbon dioxide would be delivered and stored as a liquid in a tank. Redundant carbon dioxide evaporators would convert the liquid into a gas. The carbon dioxide gas would be mixed into the softened water using an eductor system.

Each chemical system would be equipped with redundant metering pumps to allow for equipment maintenance or failure. The metering pumps would be sized to allow injecting the maximum chemical dosage at the maximum plant flow rate. A storage tank for each chemical system would be sized to provide approximately 30 days of operational storage at the average chemical usage rate. An 8,000 gallon storage tank would be required for the sodium hydroxide. A 100,000 pound storage tank is recommended for the liquid carbon dioxide.

Filtration/Clarification Equipment

The fine sand from a pellet softener has an average size of 0.3 mm or 300 microns. However, the sand will have a particle size distribution where some percentage is larger and smaller than 0.3 mm. Sand and pellets from the pellet reactors can potentially be carried over the top of the reactor into the reactor effluent.

The sand solids carryover can potentially abrade and damage the existing downstream membrane filters if significant quantities come in contact with the MF filters. The amount of solids carryover is expected to be minimal, and the sand is likely to settle out in the DAF Tanks and chlorine contact basin before the water reaches the membrane filters due to the reduced specific gravity of the aerated water. Pilot testing is recommended to determine the amount of solids carryover that can be anticipated and to determine whether the media will settle out prior to reaching the membrane filters.

Should a separate process for solids carryover removal be required, an option for the carryover removal is the use of coarse-media granular media pressure filters. The pressure filters would be designed for solids carryover removal only and would not replace the existing pretreatment facilities. Equipment required for this option include pressure filters, a backwash tank, a backwash pump and associated piping. Another approach could be to replace the strainers ahead of the MF filters with different strainers that can remover particles down to approximately 100 microns.

Conceptual Site Layout

The pellet softening system would be located downstream of the Lopez Reservoir and upstream of the existing Intake Flow Meter Vault. A potential location for the pellet softening system is the open area north of the existing solids drying basins and west of the main treatment facility. The total footprint of the conceptual 4.5-MGD Pellet Softening Facility would be approximately 85’ x 70’. This includes space for the source water pumps, pellet reactors, a small control building, chemical equipment and storage tanks and dumpsters on a dumpster pad. Space for pressure filters and backwash facilities for solids carryover removal are not included in the footprint.

Estimate of Probable Cost

Pellet Softening Facility Conceptual Construction Costs

The estimates of probable construction costs for the Pellet Softening Facility were developed based on equipment supplier's budget prices, typical unit costs and construction costs for similar facilities. The estimates reflect 2008 dollars (ENR for Los Angeles = 9224, May 2008) and planning level accuracy. A total of 45 percent is added to the estimated cost to provide an allowance for taxes (8 percent), General Contractor overhead and profit (12 percent), and contingencies (25 percent). Additional project costs were estimated as a percentage of construction cost for engineering (10-percent), construction management (10-percent) and legal and environmental (5-percent).

The following table provides a summary of the conceptual opinion of probable construction cost of a 4.5-MGD Pellet Softening Facility.

Table 3: Pellet Softening Facility Conceptual Capital Cost

ITEM DESCRIPTION	Conceptual Cost ($) (4.5 MGD)
Site Work and Paving	$23,000
Yard Piping, Source Water Pump Station	$245,000
Pellet Softening Process Equipment	$2,800,000
Chemical Systems	$369,000
Small Process Building	$50,000
Electrical/Instrumentation	$870,000
Subtotal	**$4,357,000**
Contingency, OH&P @ 45%	$1,961,000
Conceptual Construction Cost	**$6,318,000**
Engineering, CM, Legal, Environmental @ 25%	$1,580,000
Conceptual Project Cost	**$7,900,000**

Pellet Softening Facility Conceptual Operating Costs

Estimated operation and maintenance (O&M) costs for the Pellet Softening Facility are described below. The O&M costs include labor, power use, chemical and sand use, maintenance materials and pellet disposal. The O&M costs are based on an average plant flow of 4.5 MGD, softened water flow of 3 MGD and operation of the facility for 365 days per year. The O&M costs for the Pellet Softening Facility are described below and summarized in Table 3.

Table 4: Pellet Softening Facility Conceptual Operating Costs

O&M Cost Component	Probable Annual Cost ($/yr)
Power	$47,000
Chemicals and Sand	$231,000
Labor	$30,000
Pellet Disposal	$39,000
Maintenance Materials	$10,000
Total	**$357,000**

Power Costs

The energy use for operating the Pellet Softening Facility would mainly be from operating the source water pumps. Assuming an average flow rate of 3 MGD, a lift of approximately 75 feet, and a power rate of $0.10 per kilowatt-hour, the probable annual power costs for the Pellet Softening Facility are $47,000.

Chemical Costs

Chemical usage for the Pellet Softening Facility alternative includes addition of sodium hydroxide to the feed water and carbon dioxide to the softened water for pH reduction. Sand is also added to make up for sand discharged with the pellets.

The sodium hydroxide addition cost is $108,000 per year at a dosage rate of 70 mg/l and chemical cost of $0.17 per pound.

The average carbon dioxide cost is $46,000 per year at an average dosage rate of 50 mg/l and chemical cost of $0.10 per pound.

The average sand replacement cost is about $77,000 per year at an average replacement rate of 77 tons per year and cost of $1000 per ton.

The total probable chemical and sand cost for the Pellet Softening Facility alternative is $231,000 per year.

Labor Costs

The Pellet Softening Facility would be fully automated and should not require additional plant staff to be onsite beyond the current 8-hour staffed period. The labor involved in operating the facility would include loading sand into the reactor inlet hopper, washing down of the pellet disposal facility, receiving chemical deliveries and maintaining pumps and electrical equipment. An additional part-time plant maintenance staff person may be required for the additional labor associated with the operating and maintaining the pellet softening system. Labor costs for additional part-time staff is assumed to be $30,000 per year.

Pellet Softening Waste Disposal

The amount of waste solids generated from the pellet softening process is estimated to be 1.412 pounds per 1000 gallons of softened water, or about 2.1 tons per day (767 tons/yr) for a softening system flow rate of 3 MGD. The solids would be collected and trucked to a suitable receiving site. The volume and weight of solids would dictate a full truck haul of solids approximately once a week and would vary depending on the source water quality and the amount of waste storage available onsite.

The waste solids consist of clean sand particles with a coating of calcium carbonate. The material is suitable for use as a soil amendment to add calcium to soil. The pellets could also be used as a bedding material for pipes, mixed into road aggregate or used as a sand substitute. If no use can be found for the material, it can be sent to a landfill. The estimated operating costs of the pellet softening waste disposal, assuming worst case of having to haul and dispose of the pellets at a landfill, are $39,000 per year based on solids disposal costs of $50 per ton.

Maintenance Materials Costs

The maintenance materials costs are estimated at 2.5% of the cost of the process equipment that requires routine maintenance such as pumps, valves, electrical equipment, etc. The estimated maintenance materials costs are $10,000 per year.