Section 6: Overview of Relevant Treatment Technologies

Several water supply alternatives require treatment to meet CCSD's water quality objectives. This section provides a brief overview of the technologies available for desalination and water softening which may be used by CCSD to improve water quality.

6.1 Seawater Desalination Technologies

Seawater contains a significant amount of dissolved solids. Removal of dissolved solids from this water is important to enable its use for potable and non-potable applications. There are a number of treatment technologies currently available for treatment. Because CCSD's proposed seawater desalination plant has a limited capacity, membrane technologies, particularly reverse osmosis and nanofiltration, are the preferred treatment technologies. This section provides a brief overview of each technology and summarizes their costs and applicability.

Although these technologies can effectively remove dissolved ions, some water quality issues need to be addressed prior to choosing a technology. For example, these technologies often generate a large volume of concentrate containing very high concentrations of ions. These ions, at elevated concentrations, precipitate from the process concentrate.

6.1.1 Reverse Osmosis

Reverse osmosis (RO) uses a membrane that is semi-permeable, allowing the fluid that is being purified to pass through it, while rejecting the contaminants that remain. RO removes virtually all organic compounds and 90 to 99 percent of all ions, as well as 99.9+ percent of viruses, bacteria and pyrogens. Generally, RO will remove substances with a molecular weight of greater than 150-250 daltons. The separation of ions with RO is aided by charged particles. This means that dissolved ions that carry a charge, such as salts, are more likely to be rejected by the membrane than those that are not charged, such as organics. The larger the charge and the larger the particle, the more likely it will be rejected.

RO systems include a pump, a pressure vessel, and a membrane. The feed water is pumped into the vessel where it is pressurized against the membrane. The high-pressure pump supplies the pressure needed to enable the water to pass through the membrane and have the salts rejected. This pressure ranges from 100 to 400 psi for brackish water and from 800 to 1,200 psi for seawater.

Most RO systems use a process known as crossflow to allow the membrane to continually clean itself. As some of the fluid passes through the membrane the rest continues downstream, sweeping the rejected species away from the membrane. RO is dependent on the driving force of pressure to push the fluid through the membrane. The higher the pressure, the larger the driving force. As the concentration of the fluid being rejected increases, the driving force required to continue concentrating the fluid increases.

As a portion of the water passes through the membrane, the remaining feed water increases in salt concentration. At the same time, a portion of this feed water is discharged without passing through the membrane. The amount of the feed water discharged to waste in this brine stream varies from 20 to 70 percent of the feed flow, depending on the salt content of the feed water.

Pretreatment is important in RO because the feed water must pass through very narrow passages during the process. Therefore, suspended solids must be removed and the water pre-treated so that salt precipitation or microorganism growth does not occur on the membranes. Usually, the pretreatment consists of filtration and the addition of acid or other chemicals to inhibit precipitation. CCSD's proposed seawater desalination plant proposes to utilize a subsurface intake (i.e. sand filtration) to provide the necessary filtration. Post-treatment can include stabilizing the water, which has become quite aggressive due to the removal of all its salts and ions, and preparing it for distribution. This post-treatment might consist in the removal of gases such as carbon dioxide or pH adjustment.

A large selection of RO membranes are available to meet varying rejection requirements. RO can be used in residential, commercial and industrial applications to produce drinking water, industrial process water or high-purity water, as well as for desalination. Because RO is driven by pressure, rather than by an energy-intensive phase change, it is much more energy efficient compared to distillation and more efficient than the strong chemicals required for ion exchange. However, power costs are a major component of RO operating costs. In addition to power concerns, the removal of boron has become a focus of recent attention due to its presence in seawater. Although boron removal is not required in the United States, newer membranes and research on process design continues to evolve in the area of boron removal in response to regulations required by the World Health Organization (WHO).

RO facilities are commonly used for seawater desalination in remote areas such as islands and on ships. On the central coast, the Diablo Nuclear Facility has an operational RO seawater desalination system. To the north, the Marina Coast Water District has been operating a RO desalination facility along the Monterey Bay National Marine Sanctuary for several years. (The Marina Coast facility is desalinating a blend of brackish water and seawater, so its influent salt concentration is less than straight seawater.) More recently, RO desalination for larger installations in the US has come under increasing attention by public agencies as a means for solving water shortages. For example, seawater desalination via RO plants are under consideration in Huntington Beach, Carlsbad, Santa Cruz, Moss Landing, and Long Beach. More recently, Florida's Tampa Bay Water recently started operation of the largest reverse-osmosis based seawater desalination plant in the United States. However, the Tampa facility is currently experiencing operational difficulties that are currently being diagnosed by their engineers. Once resolved, the Tampa Facility plans to produce 25 millions gallons per day of potable water. The most significant environmental issue facing the use of RO for desalination is in avoiding the impingement of marine organisms at the intake, and disposal of a concentrated brine reject stream.

During the 1990's, CCSD completed design of an RO desalination facility. Although CCSD elected not to go forward with its earlier project, a certified EIR was completed along with necessary regulatory permits. Studies in support of the EIR and permits modeled the dispersion of brine discharge, and assessed the potential for any chronic toxicity effects to marine organisms. Those studies concluded that sea urchin embryos appeared to be the most sensitive indicator towards increases in salinity levels. However, salinity levels had to be at least 10 percent greater than ambient levels in order to have any noticeable effect on the sea urchin embryos[20]. In response to environmental concerns, the earlier project's brine discharge system would have kept increases in salinity levels to no more than 3 percent greater than ambient

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[20] Robert Bein, William Frost & Associates. Final Environmental Impact Report, Cambria Desalination Facility, Mitigation Measures Amended by Board Action 12/19/1994, p. 4-15.

background levels. This earlier project also anticipated recovery rates of 40 and 50 percent through the RO membranes[21]. Generally, higher recovery through the membrane of treated permeate results in higher salinity concentrations in the brine reject stream. Besides the increased salinity, anti-scaling chemicals used in the pretreatment of the seawater also need to be carefully selected in order to avoid potential environmental impacts (e.g., use of only biodegradable compounds).

Further study of CCSD's earlier desalination project was conducted during 1999[22] and 2000[23] by Kennedy/Jenks Consultants. The 2000 report included recommendations for burying the brine discharge in the surf zone, and having an offshore intake buried under sand. Additionally, subsequent research, as well as research by the US Navy, has found a newer pressure exchanger technology that further improves the energy efficiency of RO. The equipment manufacturer of the exchanger sponsored testing by the Navy's seawater desalination research facility in Port Hueneme. The Navy testing found lower RO recovery rates (around 36 percent), when used in conjunction with the pressure exchanger, resulted in the lowest energy consumption per unit of water produced[24]. Therefore, besides improved energy efficiency, the newer pressure exchanger technology may also encourage using lower recovery rates through the RO membranes, which would further lower the concentration of the brine disposal stream.

6.1.2 Nanofiltration

Nanofiltration (NF) is a form of filtration that uses membranes to preferentially separate different fluids or ions. It is not as fine a separation process as RO, but it also does not require the same amount of energy to perform the separation. NF is capable of concentrating divalent salts, bacteria, proteins, particles, dyes, and other constituents that have a molecular weight generally greater than 1,000 daltons.

NF uses a membrane that is partially permeable to perform the separation, but the membrane's pores are typically much larger than the membrane pores that are used in RO. The NF membrane will allow the water to pass through the membrane while holding back salts, and other contaminants, concentrating the reject solution. As the concentration of the fluid being rejected increases, the driving force required to continue concentrating the fluid increases. NF, like RO, is affected by the charge of the particles being rejected. Thus, particles with larger charges are more likely to be rejected than others.

NF operates at a lower pressure than RO and typically requires less energy. NF can be used for water softening and desalting and can be used as pretreatment to improve the water recovery of the seawater desalination process. The City of Long Beach is currently researching a means for desalinating seawater using a two stage NF. To date, the developers of the NF seawater desalination concept have patents that are pending, and are conducting further research. Their work may also show promise with regard to achieving boron removal.

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[21] Robert Bein, William Frost & Associates. August 1995. Addendum to Environmental Impact Report, Cambria Desalination Facility, Appendix F.

[22] Kennedy/Jenks Consultants. January 26, 1999. Project Design Report, Desalination Project Management Services, CCSD.

[23] Kennedy/Jenks Consultants. April 13, 2000. Final Project Design Report, Desalination Project Management Services, CCSD.

[24] John P. MacHarg, Energy Recovery, Inc. Exchanger Tests Verify 2.0 wkh/m3 SWRO Energy Use. International Desalination and Water Reuse Quarterly, Volume 11/1.

6.2 Water Softening Technologies

This section discusses potential groundwater treatment technologies that address groundwater quality issues that may be applicable to the development of water supply alternatives, other than seawater desalination. These alternatives are presented in Section 8.

CCSD is faced with high levels of hardness in its groundwater, particularly at Well SR-4. Hardness is caused by calcium and magnesium ions. While there is no primary or secondary MCL for hardness, high water hardness can create poor water quality from a consumer’s point of view because of calcite precipitation and excessive detergent use.

Many consumers in CCSD have installed regenerative water softeners in their homes and businesses. While the softeners do substantially reduce hardness levels, their regeneration process results in the discharge of high levels of salts to the sewer system. This salt loading to the WWTP contributes towards higher TDS concentrations within the discharge at the percolation ponds. With the recent revision of the Discharge Permit, salt management has become necessary, as previously discussed in Section 3.2.

Treatment technologies that soften water are lime-soda softening, pellet softening, and ion exchange processes; however, because of the large amount of water treatment sludge produced, lime-soda softening is not considered an appropriate technology for CCSD. Nanofiltration or membrane softeners, as discussed in the previous section, can also be used for water softening.

6.2.1 Pellet Softening

Pellet softening utilizes the same chemical principles as lime-soda softening, but does not produce an undesirable sludge. Instead, the pellet softening system consists of a gravity or pressure tank where calcium carbonate crystallizes on a suspended bed of fine sand and produces a gravel-sized pellet which can be beneficially reused.

First, the water is pretreated with either caustic soda or lime to increase the pH for precipitation of calcium hardness. The mixture is injected at the bottom of the reactor in a very turbulent and efficient mixing zone and the flow moves quickly upward through the now-fluidized bed. The calcium carbonate precipitate forms on the sand grains to form pellets with the sand at the nucleus 3 to 5 times as big as the original sand grains. Effluent is collected at the top of the unit requiring pH adjustment to stop the precipitation reaction. When the sand and calcium carbonate form a large particle, the larger heavier pellets accumulate at the bottom of the reactor and are removed and replaced by new grains of sand. The pellets, rather than sludge, are the solid by-product generated from the process.

This treatment method is generally only successful at removing calcium bicarbonate hardness. It is not appropriate for systems with high magnesium content because of potential magnesium hydroxide fouling of the reactor. Iron removal can be accomplished concurrently, while manganese usually requires post-treatment.

Pellet softener systems originated and are commonly utilized in Europe, but they are not widely utilized in the United States. There are 200 municipal installations in Europe and approximately 50 industrial installations in the United States.

The benefits of pellet softening include the following:

- Effectively reduces hardness, TDS, sodium, and chloride.
- Relatively small size of unit.
- Relatively low installation cost.
- Residual pellets are easily dewatered, then can be applied for use as agricultural lime, acid wastewater neutralizer and animal feed additive. In addition, pellets can be reused as road fill and pipeline backfill.

Either caustic soda (NaOH) or lime ($Ca(OH)_2$) can be used as the pretreatment chemical for lowering pH. Generally, caustic soda is generally easier to handle and only half the pellet volume is produced. If lime is selected, milk-of-lime produced with decarbonated water is usually less problematic.

Effluent from a pellet softening system often appears milky and filtration may be required prior to distribution.

6.2.2 Ion Exchange

Ion exchange is a physical/chemical process in which ions held electrostatically on the surface of a solid phase are exchanged for ions of similar charge in solution. The solid ion exchange particles are typically either naturally occurring inorganic zeolites or synthetically produced organic resins. The synthetic organic resins are the predominant type used today because their characteristics can be tailored to specific applications. Ion exchange is commonly used in drinking water treatment for softening, where calcium and magnesium ions are exchanged for sodium ions, and removal of arsenate, selenate, chromate, and nitrate.

Most applications of ion exchange use a system with a fixed-bed column of exchange resin. Feed water is continually passed through a bed of ion exchange resin beads in a downflow or upflow mode until the resin is exhausted and cannot accomplish any further ion exchange. Exhaustion occurs when all the sites on the resin beads have been filled by contaminant ions. The bed can then be regenerated by rinsing the column with a concentrated solution of the ions initially exchanged from the resin, known as a regenerant. The regenerant can be reused and it is sometimes advantageous to do so.

Ion exchange resins are classified as cation exchangers, which have positively charged mobile ions available for exchange, and anion exchangers, whose exchangeable ions are negatively charged. Both anion and cation resins are produced from the same basic organic polymers. They differ in the ionizable group attached to the hydrocarbon network. It is this functional group that determines the chemical behavior of the resin. There are four classes of resins: strong or weak acid cation exchangers and strong or weak base anion exchangers.

Important considerations in the applicability of an ion exchange process include water quality parameters such as pH, competing ions, resin type, alkalinity, and influent contaminant concentration. Other factors include the affinity of the resin for the contaminant, spent regenerant and resin disposal requirements, secondary water quality effects, and design operating parameters.

Many ion exchange softening processes utilize a saturated sodium chloride solution for regeneration and produce a spent regenerant, which is difficult to dispose of.