Title
Design and Analysis of Continuous High-Recovery RO Systems for Nitrate Removal in Disadvantaged Remote Communities

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Design and Analysis of Continuous High-Recovery RO Systems for Nitrate Removal in Disadvantaged Remote Communities

A thesis submitted in partial satisfaction of the

requirements for the degree of Master of Science

in Chemical Engineering

by

Abdullah B. Aleidan

2019

ABSTRACT OF THE THESIS

Design and Analysis of Continuous High-Recovery

RO Systems for Nitrate Removal in Disadvantaged

Remote Communities

by

Abdullah B. Aleidan

Master of Science in Chemical Engineering

University of California, Los Angeles, 2019

Professor Yoram Cohen, Chair

Nitrate contamination of groundwater sources is a prominent issue in remote small communities that are residing in proximity of agricultural activities. Nitrate exposure through potable water consumption poses multiple human health risks and thus impaired community groundwater sources must be treated to ensure the availability of safe drinking water. In this regard, reverse osmosis (RO) water treatment can be integrated into existing community small water systems for effective nitrate removal and salinity reduction.

RO membrane treatment offers a broad range of protection against multiple different contaminants, but high recovery operation is essential in order to reduce the challenge of managing the discharge from RO treatment. Accordingly, the present research provides a detailed investigation of the technical feasibility of high recovery RO treatment utilizing steady state RO with partial concentrate recycle. Through extensive process simulations, and based on

water use patterns in three small communities in the California Salinas Valley, it was concluded that nitrate removal can be achieved to produce treated water at a nitrate level that is significantly below the regulatory maximum contamination level (MCL). The above treatment performance was possible via single and two pass RO treatment for the small remote communities considered in the present study, while enabling sufficient high recovery that would generate a residual stream that can be accommodated in the communities' septic systems. The process configuration was optimized with respect to the number of RO elements and number of treatment passes. Detailed RO system design specifications were then developed, along with the design of treatment stages (pretreatment, RO module, and post-treatment) to meet the above-mentioned specifications. In addition, the correlation between nitrate passage and salt passage were explored for RO treatment of the source water in the study communities demonstrating that is may be feasible to predict the nitrate concentration in the permeate stream based on measurement of permeate salinity.

RO process design specifications were derived on the basis of optimizing high recovery operation for permeate production capacity for each of the study sites ranging from 1,966 to 5,600 gallons per day. System design was based on treatment of well water of nitrate level of 45 – 389.7 mg/L as NO_3^-, and salinity in the range of 564 – 1,927 mg/L as total dissolved solids (TDS). RO operation specifications under the production capacity were not to exceed average element recovery of 20%, and single-pass recovery of 15% per element. The daily concentrate stream discharge from the RO systems constituted about 4.9% - 12.5% of the community septic tank capacity for system treatment at 90% recovery operating at recycle ratios ranging from 0.67 – 2.05. Post-treatment of the produced permeate was also considered using a limestone contactor to remineralize and pH stabilize the product water.

The thesis of Abdullah B. Aleidan is approved.

Srivastava Samanvaya

Panagiotis D Christofides

Yoram Cohen, Committee Chair

University of California, Los Angeles

2019

Dedication…

The following work is dedicated to my late father, Bader Aleidan; a man of principle who dedicated his life to the betterment of his family and country.

May this work benefit those who are less fortunate than us.

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Chapter 1

1. Introduction

1.1 Motivation & Background

Groundwater nitrate contamination is a prominent issue in numerous remote small communities, particularly communities near areas with continuous agricultural activity [1-2, 40]. Nitrate exposure through contaminated potable water consumption is known to have a number of chronic effects on human health, such as methemoglobinemia and gastric cancer [60]. Nitrate contamination in rural agricultural communities' groundwater supply can be traced to multiple reasons, most notably poorly designed and self-improvised on-site septic systems that reside near the community's water table [40], and/or agricultural overapplication of nutrients/fertilizers from nearby agricultural activities that lead to nutrient leakage into the water table [61]. Furthermore, remote communities find themselves facing a water crisis due to: the lack of nearby centralized potable water supply, suitable wastewater treatment, and the high cost associated with obtaining potable water from external sources. The challenge of water sourcing is leading rural disadvantaged communities to resort to pumping untreated high salinity groundwater (500 – 3,000 ppm of Total Dissolved Solids) for domestic water use [1, 9]. This challenge is also leading disadvantaged communities to purchase purified bottled water for their potable water supply. In California, for example, more than 205 community water systems have been found (during 2002- 2010) to exceed the maximum nitrate contaminant level (MCL) of 45 mg/L as NO_3^- for [9].

The fate and transport of nitrogen in groundwater involves both nitrification of ammonia nitrogen under aerobic conditions and denitrification of nitrate under anaerobic conditions (Eqs. 1-1, 1-2) [7, 8, 40]. In general, nitrate in community groundwater results from decomposition of nitrogen-bound complex organic molecules or organic matter (OM). Molecule-bound nitrogen (from fertilizers or wastewater) is converted to ammonia (NH_3) by bacteria and fungi present in the soil and community septic system [7, 40]. Then, nitrite bacteria (Nitrosomonas) convert the ammonia to nitrite (NO_2^-), which nitrate bacteria (Nitrobacter) then converts to nitrate (NO_3^-) in aerobic environments (in the top aerated layer of the soil) [7, 8]. Denitrification occurs when certain denitrifying bacteria reduce nitrate to nitrogen gas (N_2) under anaerobic conditions present both in community leach fields (in anaerobic microsites) and septic tanks.

$$NH_4^+ + 2O_2 \xrightarrow{Aerobic\ conditions} NO_3^- + 2H^+ + H_2O \quad (1\text{-}1)$$

$$2NO_3^- + OM \xrightarrow{Anaerobic\ conditions} N_2 \uparrow + CO_2 + H_2O \quad (1\text{-}2)$$

Disadvantaged Communities (DACs) refers to the areas throughout California which most suffer from a combination of economic, health, and environmental burdens. These burdens include poverty, high unemployment, health conditions like asthma and heart disease, as well as air and water pollution, and hazardous wastes [76]. A single DAC populace varies in size from a dozen to several hundred occupants [15]. Oftentimes, these DACs do not have centralized water systems that are held up to EPA water quality standards [19], cannot sustainably manage their septic system output, or are not in reach of a municipal potable water and wastewater connections [11, 12, 76]. Conventionally, viable options for establishing a permanent safe drinking solution for small remote communities are: (a) search and drill for a new uncontaminated water source, (b) physical consolidation of water to the community from a neighboring community water system that has a clean (uncontaminated) and safe source of drinking water, or from nearby centralized treatment system connections [15, 21]. However, each of the above solutions offers challenges that are beyond the DACs' financial and human resource capability. In addition to being costly, well drilling is not guaranteed to provide safe drinking water with consistent targeted quality throughout its long-term operation. Whereas physical consolidation for the DACs in multiple cases may be a highly costly/infeasible option if the community is unable to find a nearby centralized municipal water system connection, or a neighboring community in its close proximity willing to share its water resource with the DAC [40].

1.2 Problem Statement

Nitrate contamination of groundwater is particularly challenging to mitigate in small DACs that operate their own wells and distribution systems and are removed from centralized water supply and waste treatment infrastructure. This challenge forces DAC inhabitants to rely on untreated ground water with elevated salinity and nitrate levels as their domestic water source, and bottled water as their potable water source.

Multiple treatment methods have been proposed for nitrate removal in remote communities (**§2.1.3**) including: ion-exchange (IX) [6], reverse osmosis (RO) membranes [12], electrodialysis (ED) [22], biological treatment [23], and chemical/electrochemical denitrification [24]. Such technologies (with the exception of RO membranes) have not been viable DAC treatments due to limitations based on process space/volume [23, 24], treatment process time (nitrate removal) [23], treatment extent (nitrate rejection) [14, 24, 40], capital cost [22, 23, 24], energy cost [14, 22], human resource requirements [21, 23, 24], and readiness for customization (unavailable) [40]. Ion-exchange treatment is only able to treat nitrate concentrations up to about twice the contamination levels (45 mg/L as NO_3^-) allowed by the EPA, and requires complex resin regeneration [6, 19]. Biological denitrification requires intensive post-treatment [23] for bacteria removal and disinfection. The operational complexity, maintenance, and energy costs associated with ED and chemical denitrification are beyond the capabilities of most DACs [22, 23].

Reverse osmosis (RO) membrane treatment offers multiple treatment advantages including: a broader range of protection against multiple different contaminants, excellent nitrate rejection (~96%) [12], low discharge volume output, the ability to treat high nitrate concentrations, and the capacity for customization to small-scale operations [40]. High recovery RO membrane water treatment feasibility was determined after considering community requirements and limitations discussed in detail within this study.

RO system design for nitrate removal is achievable via single or two-pass treatment in the DACs. However, product water recovery in RO treatment may be limited depending on factors such as raw feed salinity and associated limitations of system physical components (with respect to maximum allowable operating pressure and flow rates, for example). Not adhering to these factors may cause membrane fouling/scaling and/or elevated water production costs [49, 59]. A remotely-controlled and community-centralized water treatment system is needed to treat the elevated nitrate groundwater levels, reduce groundwater salinity, and provide clean potable water to remote disadvantaged communities. The treatment system of concern would have to accommodate community product demand requirements, water quality standards, water storage requirements, and waste disposal limitations.

1.3 Thesis Goal & Objectives

The goal of this research is to arrive at a process design for a high recovery reverse osmosis (RO) water treatment system for nitrate removal and salinity reduction in remote disadvantaged communities (DACs). The study focuses on the design and feasibility assessment of RO systems to achieve the above goal. Accordingly, the objectives of the study were as follows:

1- Develop specifications for RO water treatment systems for selected DACs.

2- Determine an overall RO water treatment strategy for meeting process design specifications that address product demand requirements, water quality standards, product water storage requirements, and waste disposal limitations.

3- Assess DAC RO treatment system performance via RO System Design Simulations.

4- Optimize process configurations for the RO systems with respect to number of RO elements, concentrate recycle ratio, and number of treatment passes.

5- Evaluate the relationship between RO concentrate recycling and overall RO recovery, as well as the associated impact on nitrate and salt passage.

6- Evaluate the correlation between nitrate concentration and total dissolved solids concentration in RO permeate.

1.4 Approach

The thesis work follows the flowchart presented in **Fig. 1-1**. Information acquired based on detailed community site characterization conducted by the UCLA Water Technology Research Center (UCLA WaTeR Center) was utilized as input to the design of an RO system for nitrate removal and salinity reduction. Initially, the UCLA WaTeR center conducted a survey on three north California (Salinas Valley region) study sites: Bluerock View Apartments, Santa Teresa Village, and Pryor Farms to quantify community water consumption patterns. In addition, source water quality was determined based on graph sampling in each site (**Table 4-1A**, **Appendix A**). Furthermore, a detailed description of the existing infrastructure was developed by the UCLA WaTeR Center to allow proper integration of the RO system design into the community (**Appendix F**).

The DAC RO water treatment approach consists of four parts: (1) integration of an overall RO treatment system with the existing community water system, (2) RO treatment system process design, design of treatment stages and process specifications, (3) RO module operation analysis, optimization of process specifications through RO and System Design Simulations, and (4) the development of a monitoring method for detecting permeate nitrate concentration.

The integration of the RO treatment into the DACs' water systems requires information regarding study-site materials/characteristics such as: community water demand (**§3.1.1**), community septic tank capacity for handling treatment residuals (**§3.1.2**), and suitability of existing water systems for integration with RO treatment (**§3.1.3**). A process flow diagram of the suggested treatment system is then presented (**§3.2**), and its intended treatment strategy is discussed for each of the DACs mentioned in this study.

The design of the RO treatment process strategy includes defining RO process specifications (**§4.1**) and RO process system design (**§4.2**). RO design specifications are established through demonstration of feed water quality at each study DAC (**§4.1.1**), required permeate water flowrates based on product water demand (**§4.1.2**), and the capacity of each of the study DACs' septic systems for handling RO concentrate stream at various operational conditions (**§4.1.3**). RO process design includes multiple system stages starting with a feed pretreatment stage, RO treatment unit stage, and a permeate post-treatment stage. The design of the RO pretreatment stage (**§4.2.1**) includes particulate removal through a prefilter system (300 – 5 µm diameter), and membrane scale reduction through "fresh water flush" (or FWF) and an antiscalant (AS) revisor for optional AS dosing. The pretreatment stage is followed by the RO module stage design description (**§4.2.2**). The section mentioned above illustrates the process flow diagram (PFD) of which the RO module would operate in partial concentrate recycle. A permeate post-treatment stage description is followed (**§4.2.3**). The post-treatment stage includes pH stabilization and mineral balancing through a remineralization bed. The post-treatment stage also offers optional permeate disinfection through disinfectant (chlorine) dosing if any microbial contamination is detected. The post-treatment stage also includes the addition of a residual storage tank that will collect RO process discharge (concentrate and FWF discharge) for community beneficial use (i.e. irrigation).

RO module process design (**§4.3**) presents an analysis of RO module operation in meeting the goal of the study. RO module operation analysis begins with the evaluation of high recovery operation through partial concentrate recycle given the process specifications of the design (**§4.3.1**). The analysis of the above starts with investigating the volume of residual stream generated at different levels of product water recovery at each study site. The analysis then continues to investigate the flexibility of overall operational recovery (Y) as a function of the recycle ratio (R) for choice single-pass recovery (Y_{SP}) values applicable to the single-module partial concentrate recycle model. A methodology of RO element size selection is then followed (**§4.3.2**). The element size selection process is governed by a specified range of production flowrates for each site while not exceeding maximum recovery limit of 20% per element. Next, the number of elements in series is optimized (**§4.3.3**) through the use of RO System Design Software. The number of elements was established by optimizing average element recovery (Y_i, not to exceed 20% per element) as a function of the single-pass recovery (Y_{SP}, not to exceed 15% per element) throughout the specified range of permeate production. A second-pass integration was analyzed (**§4.3.4**) in the case which elevated feed nitrate concentrations were detected. A 2^{nd} pass is proposed to when permeate nitrate concentrations were found to exceed

"Safe Point" limit of 25 mg/L as NO_3^- during the single-pass routine operation. Lastly, an assessment of use of permeate conductivity as a surrogate for nitrate concentration (**§4.3.5**) was conducted. The method utilizes RO permeate conductivity as a surrogate for permeate nitrate concentration measurements through developing a correlation between salt passage and nitrate passage in the permeate.

Finally, a general project flowchart is presented in **Fig. 1-1**, showing the overall path of research.

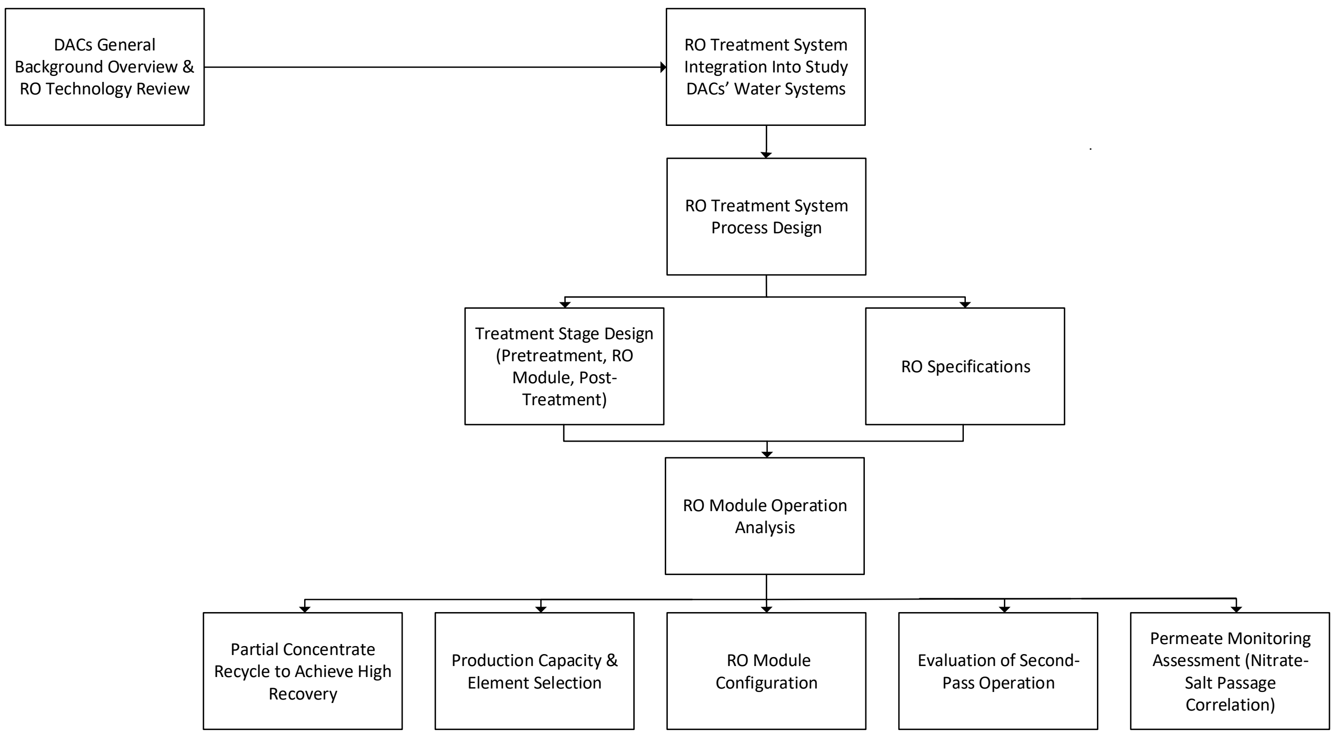

***Figure 1-1**: Overall research flowchart; Continuous High-Recovery RO Systems for Nitrate Removal in DACs.*

Chapter 2

2. Background and Literature Review

2.1 Disadvantaged Communities Background

Groundwater nitrate contamination is severe in many remote small communities, particularly adjacent to agricultural areas. These communities often lack centralized potable water supply and wastewater treatment and are dependent on groundwater for their drinking water supply. Nitrate contamination of community potable groundwater sources has been reported in various areas throughout the U.S. [1, 2]. In California, for example, more than 205 community water systems have been found (during 2002- 2010) to exceed the maximum nitrate contaminant level (MCL) of 10 mg/L as N [9]. It has been reported that about 254,000 people in California's Tulare Lake Basin and Salinas Valley are at risk due to nitrate contamination of their drinking water [10]. Disadvantaged community (DAC) groundwater nitrate contamination overview, water source options, and available nitrate removal technologies and treatment options are discussed in (section) **§2.1.1, §2.1.2** & **§2.1.3**.

2.1.1 Overview of Groundwater Nitrate Contamination in Remote Communities

Nitrate contamination of groundwater is particularly challenging to mitigate in small disadvantaged communities (DACs) who operate their own wells and distribution systems and are removed from centralized water supply and waste treatment infrastructure. Many of the affected DACs are in rural agricultural areas with low financial and human resources to mitigate their impaired water sources [11, 12]. In addition, rural communities that rely on local groundwater for their domestic supply of potable water utilize septic systems for handling their domestic wastewater (**Fig. 2-1**). Such communities vary in size from a dozen to several hundred residents. In California, for example, water systems with fewer than 15 connections are known as State Small Water systems while those with a greater number of connections are classified as Community Water Systems [13]. Because permanent solutions require significant time to plan, permit and construct, California has provided funds for interim measure to DACs in California. These measures include various emergency subsidies for temporary replacement drinking water (e.g., bottled and trucked drinking water) [10, 14, 15].

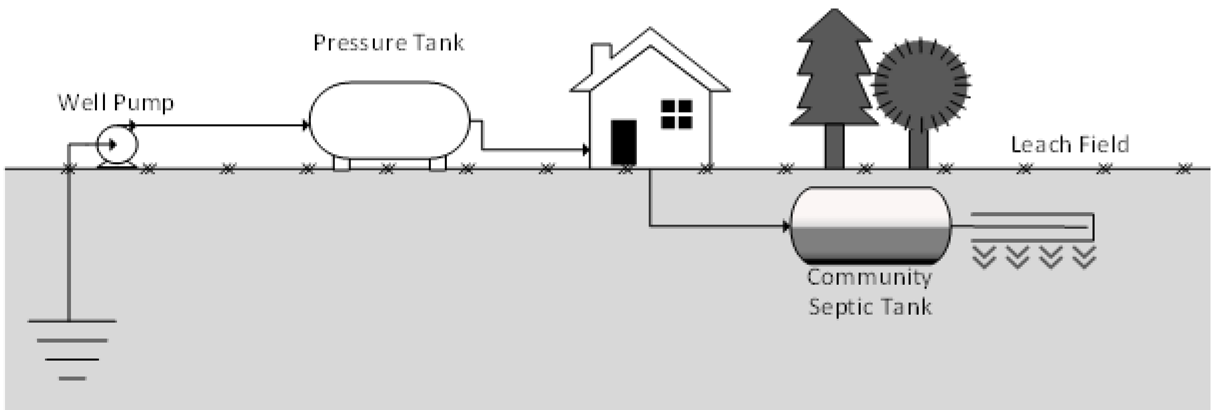

Figure 2-1: Water system in small remote communities that are without centralized water treatment or water distribution system, and are not connected to municipal wastewater system. DACs often rely on local groundwater for their domestic supply of potable water.

The choices for a permanent safe drinking solutions for small remote communities are to either: (a) search for a new clean (i.e., uncontaminated) water source (e.g., drilling a new well), or (b) physical consolidation and annexation of the community water system with a neighboring community water system that has a suitable source of drinking water or onsite treatment (in compliance with Human Right to Water law, AB 685, Chapter 524) [9, 16].

Treatment of small communities impaired well water can be either at the point-of-use (POU; e.g., treatment at the immediate use location such as under the sink) or point of entry (POE) to residential units or treatment at the wellhead or other location(s) along the distribution system prior to delivery to the community residential units [19]. While there are multiple nitrate removal technologies available commercially, DAC water treatment requires technologies that have low residual output and energy consumption footprint, are capable of producing self-sufficient daily provision of potable water for small communities (~10-40 inhabitants), and require minimal human resources to manage and operate.

2.1.2 Water Sourcing Options

The necessity of design, construction and deployment of centralized DAC water treatment systems arises from the lack of economically feasible local safe drinking water sources. The communities selected in the present study are unable to obtain water from neighboring communities because (i) DACs are too far from communities that have adequate safe source water supply, and (ii) significant capital is required for physical consolidation and water pricing is not under the community control [62].

Pipe extensions from nearby public water connections are not economically feasible for the targeted remote communities. As per a report released by the Sacramento Water District with respect to the development region of interest (Northern California), water pipeline installation capital costs are estimated to "range from $1.1 million to $4.0 million per mile" depending on desired pipe diameter [20]. Furthermore, other costs, including pumps that would convey water through the underpass, water meters to monitor and record water flow, and additional new pipes for infrastructure upgrades would additionally increase the overall cost. Moreover, the affected communities would have to abandon the use of their existing water wells, well pumps, and water tanks and begin to collaboratively pay water rates instead, which will likely be dictated by the state. **Table 2-1A** indicates monthly water rate estimates from the Cal Water website [21] for the Monterey Region (includes the Salinas Valley) based on recent community water consumption data (**§3.1.1**). It is important to note that water rates include a base water consumption cost plus a monthly water meter service charge. To determine the minimum possible monthly service charge, as dictated by the California Water Service Company for the Monterey Region, the minimum size water meter (which corresponds to one 5/8 x 3/4 inch meter per household) was used. **Table 2-1A** illustrates the minimum monthly water service rate for the communities of concern [5, 21, 62], assuming one water meter is installed per household.

Table 2-1A: Calculated[1] water consumption monthly service rates for the three communities of interest located in the Monterey Region of Northern California[2].

Community	A (Bluerock View Apartments)	B (Santa Teresa Farms Park)	C (Pryor Farms)
Average monthly consumption (gallons per month)[(a)]	26,820	41,880	76,380
Average water consumption service cost per site ($ per month)[1]	$344.36	$401.87	$539.12
Number of households[(b)] (service meters) [(c)]	11	10	8
Number of residents[(b)]	16	34	36

(a) Data accumulated from water meters installed by the UCLA WaTeR Center at each study DAC.
(b) By a previous report conducted by UCLA WaTeR Center; *"Assessment of RO Treatment of Source Water for Nitrate Removal and Management of Residuals"* [70].
(c) Thesis assumes one water meter is installed per household.

2.1.2 Nitrate Removal Technology & Treatment Options

Due to the financial burdens associated with DACs consolidation with neighboring communities and outsourcing from a county water treatment system, it was deemed necessary to assess a local community centralized water treatment system. A single treatment system at the community wellhead (upstream of the distribution system) could be an effective solution (as discussed in the present work) as it can be established in one location with effective monitoring, operation and maintenance.

[1] Water service rate = (average monthly consumption x base service rate + monthly meter service charge x # of households)
[2] Base service rate values were extracted from the schedule No. MOR-1-R for the year of 2017 over the Monterey Region Tariff Area. Information is extracted from Cal Water Website [21]. https://www.calwater.com/docs/rates/rates_tariffs/mor/20190101-Residential_Metered_Service_MOR.pdf

Multiple methods are available for nitrate removal [8] from contaminated water sources such as ion-exchange (IX) [74], reverse osmosis (RO) membranes [12], electrodialysis [22], biological treatment [23], as well as chemical/electrochemical denitrification [24]. A summary of the advantages and disadvantages of each method is presented in **Table 2-1B**.

Biological [23, 27, 28] and chemical denitrification [29-31] technologies are traditionally effective for large-scale operations that are also known to generate low volumes of residuals. However, both technologies mentioned above require suitable post filtration/treatment for the removal of suspended and dissolved residuals/trace contaminants not removed via biological or chemical treatment. Furthermore, biofilm growth in biological treatment must be managed to ensure sustainable treatment during fluctuations in water demand. In addition to biological treatment limitations, chemical treatment requires precise process control that includes pH adjustment [26] and in some cases ammonium removal [30]. There is limited commercial experience with chemical and biological treatment; such technologies require frequent operator intervention (**Table 2-1B**), and are costly [21,22]. Such technologies are not feasible for small-scale deployment and treatment in remote communities.

RO along with IX have been suggested by the EPA [71] and California State Code of Regulation §64447.2 [72] as best available technologies (BAT) for treatment of small communities' water sources that are contaminated with nitrate. IX is most viable for nitrate removal in small water systems given its simplicity, effectiveness, selectivity, and high recovery [74, 35, 36]. However, IX is limited to treatment of water with up to twice the nitrate levels as the MCL of 45 mg/L as NO_3^- [14], and requires prior softening treatment if the source water to be treated is of high hardness. Furthermore, it is important to note that IX bead/pellet regeneration requires a large amount of regeneration salts [36]. In addition to the complications associated with resin regeneration (ie. residual management, resin disposal, residual DBP formation), exhaustion of the IX exchange bed may result in nitrate leakage, thus requiring adequate real-time monitoring of the product water stream to ensure safe product water.

Unlike IX and biological/chemical nitrate removal options, RO membrane water treatment is able to provide a broad range of protection against numerous different contaminants. Nitrate rejection by RO membranes of choice has been reported to be as high as ~96% [12, 37, 38] which presents a suitable option for treating high levels of nitrate in most affected community groundwater sources.

RO system design for nitrate removal can be achieved via single or multiple stages or two-pass treatment [12]. RO product recovery is limited to various degrees depending on the raw feed salinity and scaling potential, in addition to limitations associated with physical system operating ranges (e.g. flow rate and pressure). Furthermore, a solution must be sought for the management of resulting residuals in the concentrate stream that is characterized with extreme levels of nitrate. Traditional waste disposal such as municipal sewer diversion, surface water discharge, off-site hauling via trucking or through pipe transportation, deep well injection, and evaporation ponds are infeasible for small communities given the high cost of disposal, footprint, and environmental impacts associated with said actions of disposal. In certain situations, RO residual stream may be blended with a nitrate-dilute water source for secondary (beneficial) use within the community (e.g. irrigation).

Table 2-1B: Comparison of Selected Nitrate Treatment Technologies [14].

	Ion Exchange/ Adsorption	**Low Pressure RO/ Nanofiltration**	**Electrodialysis (ED/EDR)**	**Biological Denitrification**	**Chemical Denitrification**
Limitations	Removal to waste stream	Removal to waste stream	Removal to waste stream	Biological reduction	Chemical Reduction
Pretreatment	Pre-filter, address scaling	Pre-filter 4, mitigate mineral scaling	Pre-filter, address hardness	pH adjustment, nutrient/ substrate addition; anoxic conditions	pH adjustment
Post Treatment	pH adjustment	pH adjustment, remineralization	pH adjustment, remineralization	Filtration, disinfection, excess substrate removal	pH adjustment, iron/ammonia control
Residuals	High Salinity Brine	Concentrate	Concentrate	Sludge/Biosolids	Media/Sludge
Start/Stop	Fast/Fast	Fast/Fast	Fast/Fast	Slow initially	Fast/Fast
Water Recovery	97%-99.9%	75-95%	Up to 95%	Nearly 100%	Limited field experience
Barrier protection	No	Yes	No	No	No
Advantages	Selective (e.g. nitrate, arsenic); co-removal of some contaminants; high recovery (~100%); low residual volume; low complexity	Multiple contaminants removal; salinity reduction; recovery well above 90% in some cases; low to moderate complexity	Multiple contaminants removal; salinity reduction; less prone to silica scaling; high recovery	Low residuals volume; co-removal of some contaminants	Low residuals volume, co-removal of some contaminants
Disadvantages	High chemical use (salt); fouling; high salinity brine waste; potential nitrate peaking; potential DBP formation from resin residuals; resin disposal; complex resin regeneration	Moderate energy demand; fouling; concentrate waste disposal.	Moderate energy demand; fouling; concentrate disposal; high operational complexity and maintenance	Substrate/ nutrient addition; complex, sensitivity to env. conditions; potential nitrite formation; significant post-treatment	Inconsistent nitrate removal; potential nitrite and ammonia formation; pH and temp. dependence; possible need for iron removal

2.2 Reverse Osmosis

Reverse Osmosis (RO) membrane separation is reported to be amongst the most efficient separation methods available [4, 51]. In water treatment, RO membrane technology is utilized to separate solutes, such as dissolved solids, inorganics, and a wide range of organics (high rejection of organics with molecular weights higher than 100 g/mol [51]). The separation process is conducted through passing feed so to provide water to permeate through the membrane, while rejecting the solute. The rejected brine (or concentrate) exits the process as discharge. RO principles and guidelines, concentration polarization, high recovery desalination, recovery limitations, and membrane elements are discussed in **§2.2.1, §2.2.2, §2.2.3, §2.2.4,** and **§2.2.5** respectively.

2.2.1 Reverse Osmosis Principles & Guidelines

Reverse osmosis (RO) is a separation process in which pressure is applied to a feed solution in a channel having a semipermeable membrane that allows the permeation of the solvent to produce a permeate stream, and a reject stream (i.e. retentate or concentrate) [3]. For example, RO in water desalting utilizes membranes that are permeable to water but impermeable to salt [4]. In the RO process, the applied pressure, P, must be greater than the solution's osmotic pressure, π (non-zero permeate flux). Osmotic pressure, π *(psi)*, for dilute solutions can be characterized by the van't Hoff equation in which, i, is the can't Hoff factor, C_{sol} $(\frac{mol}{L})$, is the solute concentration, R $(1.206\ \frac{L\cdot psi}{mol\cdot K})$, is the ideal gas constant, and T(K), being the temperature. Osmotic pressure can be defined as:

$$\pi = iC_{sol}RT \tag{2-1}$$

Membrane water permeability, L_p ($\frac{L}{m^2 \cdot h \cdot psi}$), is a measure of the RO membrane's ability in allowing the passage of water through the membrane and into the permeate stream. Membrane permeability is a variable that defines the flux through the membrane, J_w ($\frac{L}{m^2 \cdot h}$), where the flux is a function of the permeability times the net driving pressure defined as:

$$Jw = L_p(\Delta P\text{-}\sigma \cdot \Delta\pi) \quad (2\text{-}2)$$

with ΔP *(psi)* being the feed side and permeate side pressure deficit, σ being the salt reflection coefficient which is assumed to be unity (~1) for RO membranes, and the feed side and permeate side osmotic pressure difference $\Delta\pi$ *(psi).*

The intrinsic salt rejection, R_s, is a measure of the membrane's ability to avert salt from passing through the membrane into the permeate stream. The intrinsic salt rejection by an RO membrane can be defined as:

$$R_s = 1 - \frac{C_p}{C_m} \quad (2\text{-}3)$$

with C_p being the solute concentration in the permeate stream, and Cm being the solute concentration in the feed stream. The observed salt rejection is, R_0, is defined as:

$$R_0 = 1 - \frac{C_p}{C_b} \quad (2\text{-}4)$$

In which C_b is the bulk salt concentration of the membrane feed side.

The overall RO recovery, Y, is a measure of the volumetric flow of permeate, Q_p (Gallons per day, GPD), recovered relative to the feed flow, Q_{f0} (GPD), defined by:

$$Y = \frac{Q_p}{Q_{f0}} = 1 - \frac{Q_C}{Q_{f0}} \quad (2\text{-}5)$$

Where Q_C is the retentate or concentrate flow rates.

RO separation processes traditionally operate in a cross-flow scheme where the saline feed water enters the membrane feed channel at high pressure and flows tangentially along the membrane surface and then exits the membrane channel as retentate of high solute concentration, while the high operating pressure of the operation induces water permeation through the membrane. **Fig. 2-2A**.

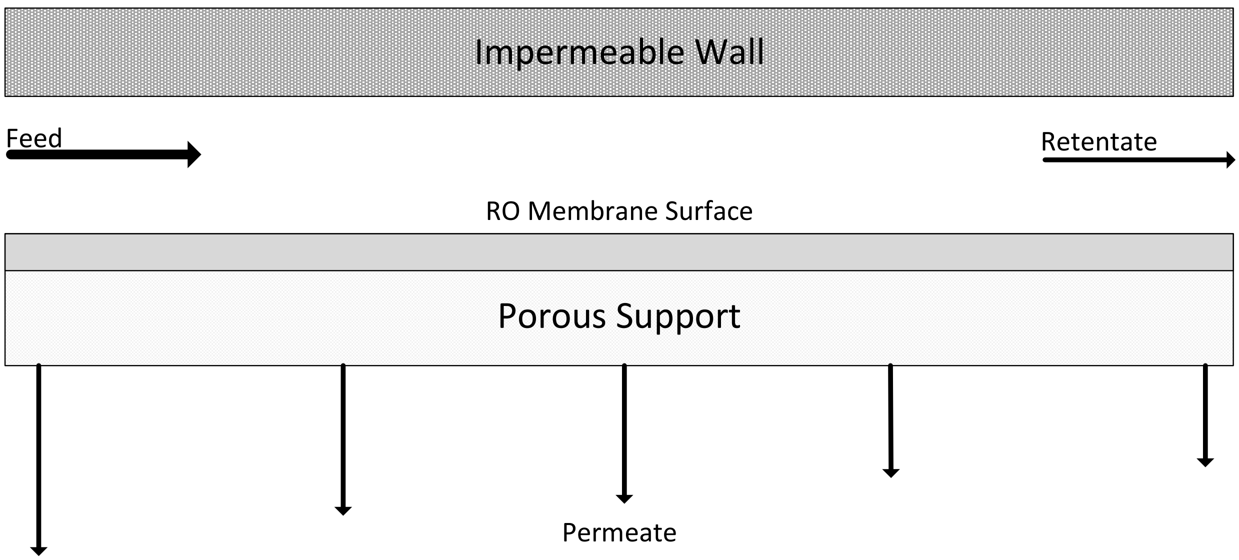

***Figure 2-2A**: General schematic of cross-flow RO membrane process.*

When treating large volumes of feed water, spiral-wound membrane modules are often used because of their large ratio of membrane surface area to membrane volume. Spiral-wound modules consist of many alternating layers of RO membrane sheets, and mesh spacer sheets wrapped around a central channel, all of which are encased within a rigid plastic shell. The spacer sheets (spacers) provide the channels through which feed and permeate water can flow. Most large-scale RO desalination plants use a multistage arrangement of spiral-wound modules connected in series with each stage containing modules in parallel as needed based on the expected flows. As permeate separation from the feed is achieved, the retentate volume decreases; often requiring fewer modules in parallel in the second stage (and the following stages if applicable) in order to maintain the required crossflow velocity [51]. Typical two-stage RO desalination illustration is presented in **Figure 2-2B**.

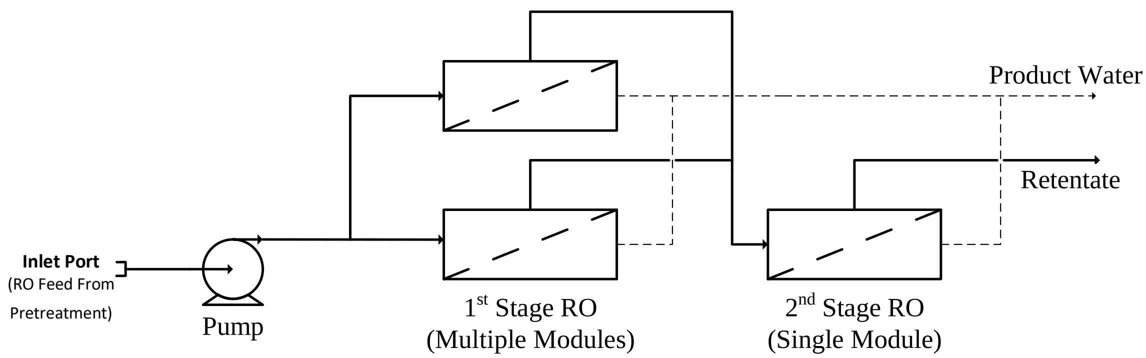

Figure 2-2B: *Typical two-stage (2:1) RO desalination illustration.* ***Pretreatment:*** *the process in which large particulates and debris that could damage or foul the RO membranes are removed from the RO feed.*

2.2.2 Concentration Polarization

Concentration Polarization is commonly known as the phenomena in which salt ions accumulate near and at the membrane surface due to the separation of solute from solvent, which in turn increases the solute concentration at the membrane surface and vicinity. The concentration polarization (CP) modulus is defined as the concentration increase at the membrane surface relative to the bulk and is often approximated by the film model [51]:

$$\text{C.P.} = \frac{C_m}{C_b} = 1 - R_o + R_o exp(\frac{J_w}{k}) \quad (2\text{-}6)$$

where C_m and C_b are the solute concentrations at the membrane surface and the concentration in the bulk, respectively, R_o is the observed salt rejection, J_w is the permeate flux, and k is the solute feed-side mass transfer coefficient.

The extent of concentration polarization gradually increases as the feed progresses along the membrane channel towards the exist region which in turn leads to a gradual increase in concentration and osmotic pressure at the membrane surface along the channel. As a result, the effective net driving pressure (i.e. $Jw = L_p(\Delta P\text{-}\sigma\cdot\Delta\pi)$) for permeation decreases and thus the permeate flux also decreases towards the exit region as illustrated in **Fig. 2-3:**

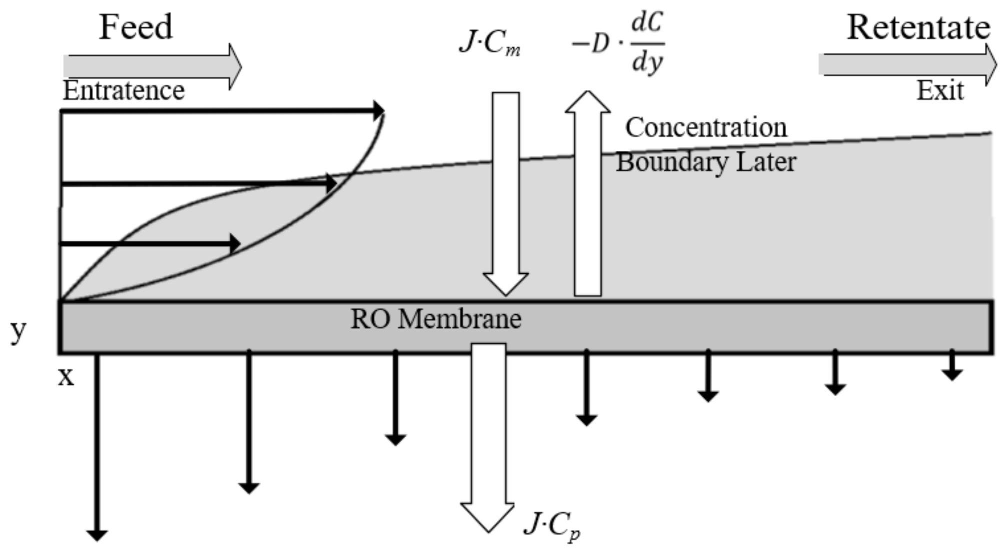

Figure 2-3*: Illustration of cross-flow in RO channel depicting the formation of a concentration boundary layer that increases with increasing x.*

2.2.3 High Recovery Desalination

Conventionally, elevated permeate recovery (50% and higher) in brackish water can be achieved through numerous system configurations, but most notably through utilizing systems that have multiple stages in the series configuration (**Fig. 2-2**); or through one-module systems with multi-element operation in series (**Fig. 2-4**) and/or in the mode of partial concentrate recycling.

In RO operation where high production capacity is targeted, high recovery desalination is achieved through the multi-stage model. In a multi-stage process the number of stages defines how many pressure vessels in series the feed will pass through until it exits the system and is discharged as concentrate. Each stage consists of multiple pressure vessel-containing modules in parallel, where a single pressure vessel may contain up to 6-element in series (in the case of brackish water) [51]. RO plants employ a number of parallel modules per stage to increase the production capacity, whereas the number of stages in series dictates the extent of recovery desired by the plant. **Table 2-2A** illustrates the range of achievable overall system recovery (Y) and the number of stages, pressure vessels, and elements needed to achieve said recovery range.

Table 2-2A: RO system recovery range for brackish water RO desalination as a function of number of stages containing single pressure vessels, and of number of elements (***20%*** recovery per element limit) in series contained in said pressure vessels. (Adapted from [51])

System recovery (%)	Number of stages (6-element vessels)	Number of elements in series
40 - 60	1	6
70 - 80	2	12
85 - 90	3	18

In regard to RO systems that are designed for low-capacity production (domestic systems, ~1,000-10,000 GPD [51]), it is recommended [51] to use a system that employs the use of a concentrate recycle stream into the RO feed stream in order to increase the overall operational recovery. Operating low capacity RO processes at high recovery can be achieved in single module systems (Fig. 2-4).

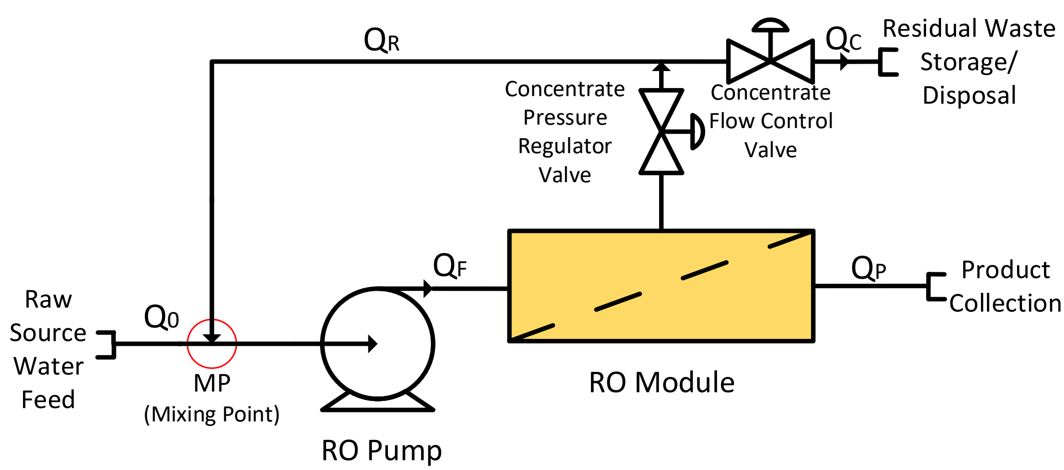

Figure 2-4: *Typical single module (multi-element) high-recovery RO desalination with recycle illustration.*

High recovery in single-module systems can be achieved through employing a recycle stream operating at a design recycle ratio (Eq. 2-7). The module consists of a pressure vessel with up to eight membrane elements connected in series [51]. The module's permeate (exit) port collects the permeate from all the elements' product tubes continuously through RO operation. The RO concentrate leaves the RO concentrate outlet port at a pressure less than that of the feed inlet, controlled by the concentrate pressure regulator valve. The concentrate flowrate (Q_C in **Fig. 2-5**) flowing out the module and into the residual waste stream which is regulated by the concentrate flow control valve. The system recovery (Y) is dictated by the concentrate flow control valve and must not exceed the design set value. In single-module multi-element systems, concentrate recycle is required to achieve recommended single-pass recovery (Y_{SP}) [51]. To achieve high system recovery (50% and higher), part of the concentrate stream resulting from RO separation is recycled and added to the suction side of the high-pressure RO pump at the indicated mixing point (MP) on **Fig. 2-4** which increases the feed flow to the module.

It is important to note that in RO operation with partial concentrate recycle into the feed stream increases the feed bulk solute concentration as well as the solute concentration at the membrane-surface. Conventional scale control strategies (feed filtration, use of antiscalant, pH adjustment, and operating below the critical scaling threshold) can partly alleviate RO limitations places by membrane mineral scaling; allowing RO desalination of brackish water up to a moderate recovery range of 60-85% [49, 50].

The previously mentioned recycle ratio (Eq. 2-7), and the single-pass product recovery [75] through the membrane array (Eq. 2-8) can be defined as:

$$\text{Recycle Ratio, } R_{\text{Ratio}} = \frac{Q_R}{Q_0} \qquad (2\text{-}7)$$

$$\text{Single-Pass Recovery, } Y_{\text{SP}} = \frac{Q_P}{Q_F} \qquad (2\text{-}8)$$

where Q_R, Q_0, and Q_F are the recycle stream, the raw feed stream, and the feed to the membrane stream flowrates (GPD) respectively. Furthermore, upon conducting a material balance about the mixing point (MP on Fig. 2-4); the concentrate recycle stream flowrate (Q_R), with respect to the overall and the single pass water recoveries (Y and Y_{SP}), can be written as:

$$Q_R = \frac{Q_P}{Y_{SP}} - \frac{Q_P}{Y} \tag{2-9}$$

The above equation can be rearranged to yield the overall recovery, Y, which produces:

$$Y = Y_{SP}\,(1 + R_{Ratio}) \tag{2-10}$$

2.2.4 Recovery Limitations

Total recovery is limited fundamentally due to: i) decrease the effective net driving pressure for permeation with rising recovery and ii) mineral salt scaling [59]. As the retentate increases in concentration with high recovery, so does the effect of concentration polarization, and so does the reduction of the effective pressure driving force available for producing the required flux of water through the membrane. Recovery is ultimately limited by the available pumping power and/or maximum operating pressure of the vessels used in a specific process. Therefore, the theoretical highest achievable recovery corresponds to that at the moment when the osmotic pressure resulting from the retentate concentration accumulation approaches the pressure vessels' highest operating pressure. The above is theorized with the assumption that negative process effects such as scaling, fouling, swelling, or scratching of the elements used in the process are mitigated properly. When the osmotic pressure surpasses the allowable operational pressure set by the RO elements & pressure vessels of use; the flux of water through the membrane will decrease. This inefficiency in operation reduces permeate flows, and can lead to membrane scaling and fouling if prolonged. Conventionally, operating the system at high pressures (near the pressure vessel's maximum allowable pressure) has proven to have high utility and maintenance costs [51].

Whereas in regard to mineral salt scaling, it can be defined as the process of which sparingly soluble salts crystallize on RO membranes effectively causing the decrease of permeate flow through the membrane. Crystallization can occur in both the bulk solution (homogenous) and/or on the membrane surface (heterogeneous). Crystallization occurs when the saturation of a sparingly soluble salt is exceeded. A measurement of the degree to which the saturation is exceed for a given salt is known as the saturation index (SI) to which its defined as:

$$\text{Saturation Index, SI} = \frac{IAP}{Ksp} \tag{2-11}$$

in which IAP is the ion activity product, and K_{sp} is the solubility product of said salt. Once scaling is found to occur periodically in an RO process (e.g. high CP modulus number), the use of antiscalants is then advised. Some mineral salts (such as calcite) are generally soluble upon decreasing the pH of the feed through acid dosing (HCl, H_2SO_4) [49], whereas others (example: gypsum and brite) are pH insensitive and their scaling cannot easily be managed by pH adjustment and would require the use of antiscalant if the saturation index is exceeded in routine operation [59].

Additional factors that may lead to recovery limitations is biofouling. Biofouling occurs when microorganisms (such as bacteria or algae) attach to and grow on the membrane surface, which leads to reduced membrane surface area resulting in an overall decrease in water permeation.

2.2.5 RO Membranes

RO membranes are thin film composites of an aromatic polyamide active layer (~200 nm thick) supported by a porous polysulfone layer (~60 μm) which in itself is supported by a non-woven fabric layer underneath (~150 μm) as shown in Fig. 2-5 [59]. The aromatic polyamide thin film is where the separation occurs, whereas the two other layers are present to provide structural support without impeding solvent permeation through the membrane.

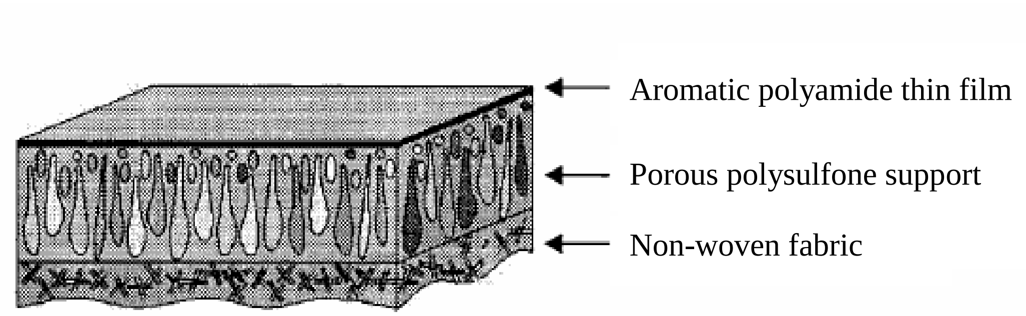

Figure 2-5: *Cross section of a typical RO membrane showing layered structure.*

The aromatic polyamide thin film is a nonporous, dense film of which permeants are transported through by diffusion under the driving force of a pressure gradient created by the feed pump. The separation of various components of a solvent-solute mixture is directly related to their relative transport rate within the membrane, a rate that is determined by the component's diffusivity and solubility in the membrane [49, 59].

Chapter 3

3. Community RO System Integration

3.1 Case Study: Remote Communities in Salinas Valley

Three remote disadvantaged communities (DACs) in the Salinas Valley, located in northern California, have been chosen to be study sites for the Distributed Drinking Water Treatment Systems Project by the UCLA Water Technology Research (WaTeR) Center. These communities are given the names Bluerock Apartments, Santa Teresa Park, and Pryor Farms. The locations of these DACs are shown in **Fig. E-1**. It is proposed to install high recovery RO groundwater treatment systems for nitrate removal and thus a detailed evaluation was undertaken to determine the specifications and feasibility of deploying such treatment system in the above communities. The source water of the communities was found to have nitrate ion concentration in excess of the MCL of 45 mg/L as NO_3^- (**Appendix A**).

In order to design feasible water treatment systems that meet the DACs' needs, the DACs' water consumption data was assessed and detailed information was compiled regarding the DACs' existing septic tank volumes, and water systems [40]. Detailed information provided in the following subsections (**§3.1.1, §3.1.2 & §3.1.3**) expand thoroughly on important community characteristics such as community water demand, community septic tank limitations, and existing water systems to be integrated into the design.

3.1.1 Community Water Demand

In order to determine water use patterns in the study communities, smart (wireless) water meters were installed in each of the communities. The water use data was transmitted to a remote server and analyzed over a two-year period. **Table 3-1A** illustrates a summary of water consumption data collected from water meters installed by the UCLA WaTeR Center at the study communities. Water consumption peaks significantly above average water consumption were encountered. It was found that maximum water demand fluctuations happened primarily during the months of July and August (~40-130% increase in consumption).

Table 3-1A: Summary of daily water consumption data in the study communities [40].

Community	Population	Number of Households	Average Water Consumption (Gal/Day)	Average Water Consumption Per Person (Gal/Person/Day)	Average Water Consumption Per Household (Gal/household/day)	Maximum Water Consumption (Gal/Day)
Bluerock View Apartments	16	11	894	55.88	81.27	1,996
Santa Teresa Farms	34	10	1,396	41.06	139.60	2,826
Pryor Farms	36	8	2,546	70.72	318.25	3,594

3.1.2 Septic Tank Limitations

Remote disadvantaged communities (DACs) that are not connected to a centralized municipal sewer system utilize septic systems for wastewater removal and storage. Community septic systems direct community wastewater to a septic tank located underground [40], as illustrated by **Fig. 2-1**. A septic tank is generally recommended to be of a volume such that a hydraulic retention (**Eq. 3-1**) of 1-3 days is recommended to insure sufficient anerobic digestion, and sedimentation of Organic Matter (OM), or sludge, into the bottom of the tank [40, 42]. In addition, the septic tank has to be sized to accommodate the incoming community wastewater.

$$\tau = V_{tank}/Q_{waste} \tag{3-1}$$

The community septic tank volumes were reported to be 4,500, 5,000, and 5,000 gallons for Bluerock, Santa Teresa, and Pryor Farms respectively.

3.1.3 Existing Water Systems & Topography

The three Northern California (Salinas Valley region) pilot DACs have been self-reliant in extracting their non-potable water capacity from their local wells. The existing water systems in Bluerock, Santa Teresa, and Pryor Farms serve 16, 34, and 36 inhabitants respectively. Submerged well pumps in all site wells serve to extract water that is then fed the communities' service tanks (feed and/or pressure tanks, site-dependent). Each site contains a water distribution system for water delivery to the community. Schematic illustrations of existing on-site water systems layouts for the three DACs are provided in **Appendix E**, **Figures E-1A** to **E-1C**.

Table 3-1B: Current water system components in operation at all DAC study sites.

Community	Blue Rock View Apartments	Santa Teresa Park Farms	Pryor Farms
Number of inhabitants (households)	16 (11)	34 (10)	36 (8)
Well Pump Location	Submerged	Submerged (off-site)	Submerged
Pressure Tank Volume (Gal)	4,000	4,000	4,000
Septic Tank Volume (Gal)	4,500	5,000	5,000
Additional on-site equipment	Ion-exchange system Pressure tank	Pressure tank centrifugal pump Atmospheric pressure-feed tank (5,000 Gal)	Pressure tank

3.2 Overall RO Treatment System Integration (Process Flow Diagram)

The water treatment system design of the three Salinas Valley study DACs (Bluerock View Apartments, Santa Teresa Farms Park, and Pryor Farms) has multiple design objectives to achieve (**§1.3**). The treatment system is to operate at a high recovery and of a small residual footprint, and integrate with the existing water systems, and to continuously monitor water quality. A wellhead water treatment is to be conducted whereby the treatment system is to include the following stages: pretreatment, RO membrane module, residual management, and post-treatment. An overall system Process Flow Diagram (PFD) is shown in **Fig. 3-1**. The diagram's equipment tables, **Tables F-1** to **F-3** are provided in **Appendix F**; showing all system components and their operational stream parameters and specifications.

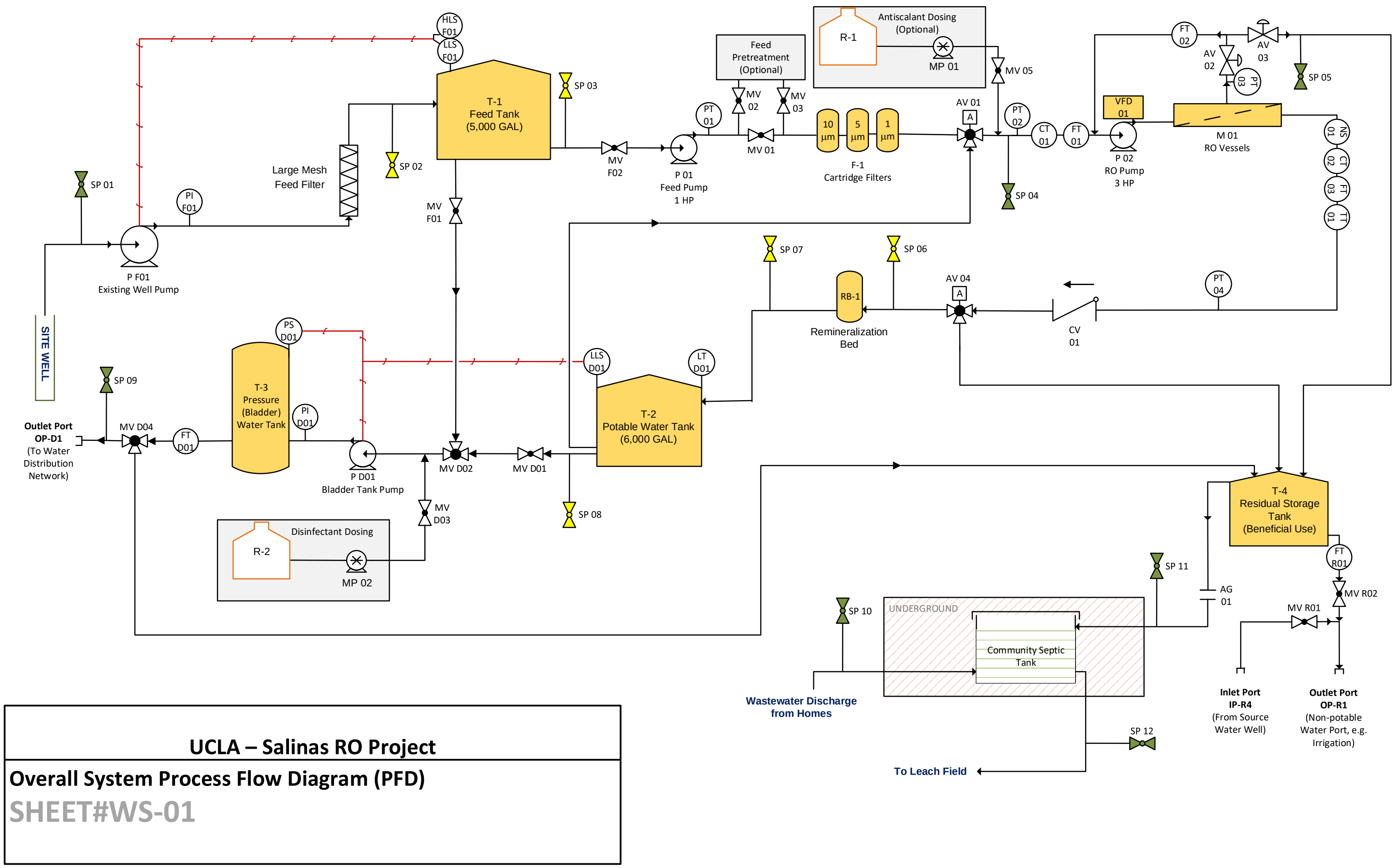

***Figure 3-1**: Proposed continuous high-recovery RO system for nitrate removal in Disadvantaged Remote Communities (DACs) Process Flow Diagram (WS-01, Worksheet-01) to be implemented in all study remote communities. The system design includes pretreatment, RO treatment, residual management, and post-treatment & distribution.*

(Legend: PI-i = pressure indicator, PT-i = pressure transmitter, PS-i = pressure switch, CT-i = conductivity transmitter, FT-i = flow transmitter, TT-i = temperature transmitter, NS-i = nitrate sensor, LLS-i = low-level switch, HLS-i = high-level switch, MV-i = manual valve, AV-i = automated valve, CV-i = check valve, AG-i = air gap valve, SP-i = sampling valve, P-i = centrifugal pump, MP-i = metering pump, VFD-i = variable frequency drive, T-i = Tank, F-i = filter. xx-Fi = pretreatment system component, xx-Di = post-treatment & distribution system component, xx-Ri = residual management system component)

The communities' existing submerged well pumps (P F01) will act as the system feed pump in the feed section of the design, where water will be drawn by the existing well pump and delivered to the feed tank (T-1) through a screen filter. The well pump is automated to turn on when the low-level switch (LLS F01) located in the feed tank is activated. The pump will continue to operate until the high-level switch (HLS F01) located on the same tank is activated. The water from the feed tank will then be pumped through a series of pretreatment filters through a low-power transfer pump (P 01). The pretreatment filters will consist of 10, 5, and 1 μm mesh cartridge filters that will remove suspended particles in the feed flow. It is noted that two external connection ports (MV 02 & MV 03) are to be established before the cartridge filter series. The two ports (MV 02 & MV 03) are meant to work as a connection that allows for future installation of new pretreatment components that will be used as tools to eliminated targeted dissolved solids that may risk the RO membrane integrity (e.g. green sand filter to remove dissolved iron in the feed).

After the cartridge filter series (F-1), the feed line is to have provisions for optional antiscalant injection (R-1) that will be used to limit membrane scaling and fouling. The feed is then pumped into the RO unit via a Variable Frequency Drive (VFD) RO feed pump (P 02) that will provide sufficient feed flow for the RO. The separation process begins after the RO feed stream, resulting from mixing the raw feed stream with the recycle stream prior to the RO feed pump, enters the RO unit membrane element. The RO retentate exits the RO vessels and is redirected through two actuated pressure-reducing valves (AV 02 & AV 03) to an entry point before the RO feed pump (P 02) at a design recycle flow rate, whereas the remaining concentrate is directed to a residual storage tank (T-4) for beneficial use (e.g. agricultural application), and storage.

The permeate of the RO proceeds to a lime remineralization bed (RB-1) for mineralization and pH stabilization, before entering the potable water tank (T-2) for storage. The permeate is to be monitored for salinity and nitrate concentration. Online nitrate monitoring of the permeate is carried out using an online nitrate concentration transmitter (NS 01). Water is directed from the potable water tank (T-3) to the community pressure (bladder) water tank (T-3) using a small pressurizing pump (P D01). It is noted that the water is available from the bladder tank pump (P D01) unless dictated otherwise by pressure setpoint set by a pressure sensor (PS D01) located on the bladder tank (T-3), or a setpoint dictated by a low-level switch (LLS D01) located in the potable water tank (T-2). The line before the bladder tank pump (P D01) contains an entry port (MV D03) to when disinfectant injection is needed. Water from the bladder tank (T-3) is then set for distribution and consumption.

Residual storage tank (T-4) includes entry ports from the RO permeate line (actuated by AV 04) and from the bladder tank (T-3) in post-treatment & distribution (actuated by MV D04). The residual tank (T-4) has an overflow exit port leading to the community septic tank. The residual tank is to be utilized for beneficial use, and as a storage tank for excess residual volume as a buffer for the community septic tank.

Chapter 4

4. Process Design & Analysis

4.1 RO Process Design Specifications

In order to fully optimize the operation of RO treatment at the Disadvantaged Communities (DACs) of interest, site-specific design specifications were considered. The specifications dictated by the design are developed from understanding: 1) the effect of the site-specific water quality profiles on RO unit operational integrity, 2) the need of the systems production capacity to meet the communities' water demand guidelines (plus a safety factor) while maintaining element integrity through high recovery operation, and 3) the need of the RO residual product to meet the communities' septic system capacity, and the extent of high recovery operation in optimizing said septic capacity. RO process design specifications are to be simulated through RO System Design Software (CSMPro5 and OLI Studio) for further analysis in the following chapter (Results & Discussion).

4.1.1 Feed Water Quality

Community well water profile identification is essential for the design of the overall RO process. Water quality has to be reviewed from an RO system pretreatment viewpoint in order to remove any suspended particles in the stream (which will be thoroughly discussed in **§4.2.1**), as well as reviewed from an RO unit feed viewpoint in order to limit element scaling, determine the number of treatment passes, etc.

The RO unit feed analysis is done at the raw feed of the unit, as well as at the feed to the membrane (after the recycle stream mix point). The water profile of the source well is usually the same as that of the raw feed, unless ion-targeting pretreatment methods are used. The water quality profile at the source well is of the same quality profile at the raw feed of the RO unit subsection of the design (with the exception of iron ion concentration, which will be discussed in

§4.2.1; pretreatment**). **Table 4-1A** display water quality profile summaries of the three DACs' source wells sampled through 3 years of monitoring[3] (2015-2018). Complete water quality reports collected by the UCLA WaTeR Center for all sites are found in **Appendix A**. Concentrations and saturation indices near the membrane surface (post recycle mix-point, and true feed to the RO unit) are element rejection-dependent and would have to be produced through experimentation at the community, or through RO System Design Software (CSMPro5 and OLI Studio).

Table 4-1A: Summary of water quality profiles for the three DACs of concern.

		Well Source Water				
	Unit	Bluerock View	Santa Teresa	Pryor Farms (Well "L")	Pryor Farms (Well "6"*)	EPA MCL**
Turbidity	NTU	0.15	0.82	0.15	ND	-
Total dissolved solids (TDS)	mg/L	1126 - 1500	554 - 594	1091 - 1927.1	1160	500
pH		7.3	7.6	7.4	7.5	6.5-8.5
Nitrate	mg/L as ion	121.95 - 182.7	45 - 46	97 - 389.7	101.7	45
Sodium	mg/L	174	78	115	128	-
Calcium	mg/L	193	62	245	137	-
Chloride	mg/L	217	154	134	125	250
Sulfate	mg/L as ion	326	67	357	353	250
Iron	µg/L	ND	777	35	ND	300
Lead* **	µg/L	ND	ND	ND	ND	0
Copper* **	µg/L	75.1	21.8	624	624	1000
Arsenic	µg/L	2	2	1	2	10
Alkalinity	mg/L as $CaCO_3$	348	112	244	256	-
Coliform, E. Coli (Quantitray)	MPN/100mL	<1	<1	26	<1	1
Total organic carbon (TOC)	mg/L	1.7	0.5	1.1	0.7	-
$SI_{calcite}$		4.33	0.84	4.76	3.36	-
SI_{Gypsum}		0.11	0.01	0.09	0.07	-

(*) The Pryor Farms site has two operational wells for groundwater pumping: well "L" and well "6". Due to recently-elevated nitrate concentration in well "L" (389.7 mg/L as NO_3^-), the UCLA WaTeR Center has

[3] Data is based on grab sampling analysis provided by Monterey Bay Analytical Services (MBAS) and Dellavalle Laboratory, Inc. Certain concentrations indicate a range of values which were taken from 9/22/2015 to 9/15/2018 from all communities.

proposed starting RO operation at well "6" instead; (**) based on the National Primary and Secondary Drinking Water Regulations required by the EPA [13]; (***) indicates sampled collected from kitchen tap water based on the "Lead and Copper Rule" [86].

All the DACs of concern display elevated levels of nitrate and salinity concentrations in their source wells that exceed the Maximum Contamination Levels (MCLs) allowable by the EPA [19], with certain sites exceeding the allowable MCL for nitrate by approximately 8 times (Pryor Farms). Additional analytes have exceeded the MCLs such as Sulfate in Bluerock and Pryor Farms, and Iron in Santa Teresa. It is important to note that Tap Water Analysis conducted by the UCLA WaTeR Center has shown no lead or copper trace contaminants, resulting in the conclusion that the integrity of the distribution system piping within the communities is uncompromised.

In regard to the saturation indices calculated at the water source using OLI Studio; calcite crystallization is to be expected even at low recoveries, whereas gypsum may be present at high recoveries. It is important to note that calcite formation in RO processes can be addressed by lowering the pH of the feed, whereas gypsum formation would require the use of antiscalants [49, 59].

4.1.2 Product Water Demand

Community water demand was explored through installing water meters at all community water wells for community consumption monitoring. Table 3-1A (**§3.1.1**) indicates most recent (2018) water consumption data collected from the study communities (DACs). The production capacity for all communities was designed to limit continuous operation of RO module to avoid excessive startup and shutdown of the RO system which can lead to accelerated equipment wear and tear, while maintaining an apt storage capacity for emergency shutdowns in the system. The design equation for the permeate production capacity in all DACs of concern was developed to be:

$$\text{Design Production Capacity, } Q_P \text{ (GPD)} = 2.2 \cdot \text{(Average Water Demand)} \quad \textbf{(Eq. 4-1)}$$

Which translates to double the average daily demand per community plus an 11% safety factor. Assuming that the average daily consumption trend persists: the system aims to operate at steady state for a maximum of 12 hours a day to cover the community daily demand through design production capacity. It is important to note, that during the months of May to August each year, Maximum Water Consumption trends are noticed. Maximum water demand in the DACs of concern usually reaches double the average water demand throughout the year. To account for such discrepancy, a range of production capacities has been considered in all communities to ensure that the study DACs do not face water shortages or result to continuously operating the RO unit (California, Title 22 CCR §64554, New and Existing Source Capacity, [65]).

The determining of the design production capacity allows for element-type choice based on operational range of fluxes dictated by the type of water being treated by the membrane, surface area of the membrane, and the cross-flow velocity produced during operation. It is recommended that brackish water RO desalination processes adhere to flux ranges of 12-17 gfd (membrane manufacturer technical manual attached in **Appendix H**). A commercially available membrane of high nitrate rejection (96%) was chosen (CSM RE4040-BE) based on the required production capacity of each community at high recovery operation. The operational range of cross-flow velocity is to be kept at 0-0.57 m/s [52, 64]. In order to achieve RO operation at 90% recovery, the design concentrate recycle ratio (Q_R/Q_F) would be within the range of 0.69 to 1.98. **Table 4-1B** indicates the range, and limitations, of which process design specifications for RO systems are to be targeted for each community for nitrate removal and salinity reduction.

Whereas **Table 4-1C** indicates RO operation specifications for each distinct community based on their design production capacity.

Table 4-1B: Overall specification ranges and limits for RO Systems for Nitrate Removal and Salinity Reduction for DACs.

RO System Specification	Desired Range for RO System Specification in All DACs
Production to average demand ratio[(a)]	2.2
Recovery (%)	90
Flux (gfd)	12 - 17
Cross-flow velocity range (m/s)	0 - 0.57
Maximum single element recovery (%)	20
Targeted permeate nitrate concentration limit[(b)] (mg/L as ion)	25
Targeted permeate TDS[(c)] concentration (mg/L)	150
Maximum operating pressure (PSI)	350

(a) In accordance with equation *4-1*.
(b) Nitrate permeate concentration limit is less than the EPA MCL of 45 mg/L as NO_3^- to account for any future nitrate concentration increase in the community source wells.
(c) TDS = Total Dissolved Solids

Furthermore, the targeted permeate nitrate concentration resulting from RO treatment is less than 25 mg/L as NO_3^- to account for any future spikes in source well water nitrate concentrations due to high nitrate leaching into said well or other circumstances. Whereas the targeted permeate total dissolved solids (salinity) concentration after desalination is less than 150 mg/L, mimicking tap water concentrations [66]. Any increase in design permeate quality range for nitrate concentration requires the implementation of a second pass within the RO unit for further separation.

Table 4-1C: RO operation specifications for each DAC at the design permeate flow operation (routine operation) at 90% recovery using element type RE-4040BE.

RO System Specification	Study Disadvantaged Communities		
	Bluerock View	Santa Teresa	Pryor Farms
Feed flow (GPD)	2,185.30	3,412.20	6,223.56
Design permeate flow (GPD)	1,966.80	3,071.00	5,601.20
Flux (gfd)	11.57	12.04	16.47
Residual waste (GPD)	218.50	341.20	622.36
Cross-flow velocity (m/s)	0.13	0.21	0.38
Recycle ratio	1.98	1.27	0.69
Single-pass recovery (per element, %)	15.10	13.23	13.98
Number of elements	2	3	4
Element recovery (%)	16.45	15.51	18.52
Average daily demand (GPD)	894	1,396	2,546
Maximum daily demand (GPD)	1,996	2,826	3,997
Product Water Storage Tank (Gallons)	2,000	3,000	4,000

4.1.3 Capacity for Waste Disposal

The expected level of RO residuals to be expected will depend on the level of product water recovery during routine operation. It is integral to reduce the volume of residuals resulting from high recovery RO separation in order to reduce the residual volume entering the community septic tank. Increased volumes of high nitrate concentration residual into the septic tank will result in high nitrate loading into the leach fields nearby as discussed in **§3.1.2**. Given that the design recovery is to be at 90%, the RO separation is expected to have minimal residual volume with respect to the overall septic tank volume (volume percent) ranging from 4.86 to 12.45% per day as summarized by **Table 4-1D**.

Table 4-1D: Summary of residuals volume generated for treatment of feed water at 90% recovery for the design production capacity at each study DAC.

	Study Disadvantaged Communities		
	Blue Rock View Apartments	Santa Teresa Farms Park	Pryor Farms
Design Production Capacity (GPD)	1,966.80	3,071	5,601.20
Target Water Recovery (%)	90	90	90
Volume of Feed Intake (GPD)	2,185.33	3,412.22	6,223.56
Volume of Residual (GPD)	218.53	341.22	622.36
Percent of Residual Volume (to Septic Tank, per day)	4.86%	6.82%	12.45%
Septic Tank Capacity	4,500	5,000	5,000

Furthermore, the implementation of a residual tank (tank T-4 in **Fig. 3-1**) will furthermore reduce the effect of said septic tank overflowing by utilizing the RO residuals (with an option for water blending) in secondary communal use (e.g. irrigation, cleaning, etc.). The beneficial use tank (residual storage tank, T-4) will employ an overflow valve that will direct any increase in tank (T-4) capacity to the community septic tank, which will only experience the above reported (**Table 4-1D**) septic tank volume increase percentages when the beneficiary use tank (T-4) has not been used for a prolonged period of time (6-9 days). It is important to note that the residual storage tank is set at a capacity of 4,000 gallons.

4.2 RO Process System Design

Following the design specifications presented in the previous section, the RO system strategy design is to be configured. The system design strategy begins with optimizing the RO feed through pretreatment which will first employ a large mesh screen filter for large object removal (gravel, large OM, etc.). The pretreatment continues through cartridge filters for particulate removal (silt, clay, etc.), while employing a connection for additional filter installation (green sand) which is aimed for targeted species removal (iron) in specific communities to reduce the impact of the feed on the RO module. Furthermore, upon optimizing feed composition for RO treatment; the RO module design is followed by the determination of the number of elements for RO module operation at each community, and the number of passes intended for said operation in order to achieve the targeted permeate nitrate concentration limit (safe point) found in **Table 4-1C**.

Product quality (nitrate concentration) monitoring is done with the installation of a permeate nitrate transmitter that would online-transmit and record nitrate levels to a remote supervisory system at UCLA (WaTeR Center). However, given the high cost of said sensors, a method of utilizing permeate salinity levels (TDS concentrations measured through conductivity sensors) into projecting nitrate levels by establishing a site-specific salt-nitrate correlation using RO System Design Software (CSMPro5 and OLI Studio). The permeate is also designed to undergo sufficient post-treatment that aims to stabilize its pH levels through remineralization bed contact, and maintain potable water integrity from contamination through optional disinfection that is designed to maintain a disinfectant (chlorine) dose through community water network distribution.

4.2.1 Pretreatment

The standard pretreatment section of the strategy design (**Fig. 4-2A**) is designed to remove suspended particulates in the RO feed. The pretreatment section is composed of a large-mesh screen filter (300µm) which is designed to remove gravel and sand from entering the feed tank (T-1) to eliminate any threat to system pumps and equipment. The feed tank (T-1) is to be followed by a set of three cartridge filters ranging in mesh-size from 10 to 5 to 1µm aimed to remove suspended particles such as clay, silt, and any organic matter (OM) pumped from the feed tank.

A specialized pretreatment filtration addition is an available option for communities that require targeted-species removal prior to RO module operation, as a connection for additional pretreatment components is included in all DAC community designs. Santa Teresa Farms water quality data (summarized in **Table 4-1A**) reports an iron concentration of 0.7 mg/L, which exceeds the EPA's MCL of 0.3 mg/L. Although RO separation is capable of iron removal and meeting the EPA guidelines, studies show that dissolved iron in brackish water is directly proportional to calcium sulfate (gypsum) crystallization. Therefore, in order to limit gypsum scaling potential; dissolved iron at Santa Teresa RO feed must be minimalized before contacting the RO elements. It is important to note that water quality test results do not specify which type of iron is present in Santa Teresa's water sample (particulate iron, or dissolved iron). It is hypothesized that particulate iron is prevalent species due to the high turbidity or the Santa Teresa water sample, and the place of sample collection (the bottom of the community's feed tank). However, the optional addition of a green sand filter prior to the standard set of cartridge filters is found to be apt for ferrous iron removal (dissolved iron) for concentrations up to 0.5 mg/L with continuous injection of oxidant upstream, or periodic re-activation of the bed [6]. Furthermore, if the prevalent species found in the feed stream is ferric iron (particulate); it can be removed using the previously mentioned cartridge filters without the need of green sand filters.

Due to the values of saturation indices reported in **Table 4-1A**, mineral scaling of the membrane is an issue that must be targeted during pretreatment. It is hypothesized that effective membrane cleaning can be achieved by periodic "Fresh Water Flush" (**Appendix B**, *Mode: Fresh Water Flush*) at the acidic pH of the RO permeate (i.e., prior to pH adjustment via post-treatment) which can serve to solubilize and avoid buildup of foulant or mineral scale layer on the RO membrane [34]. The RO membrane module will be periodically cleaned via "Fresh

Water Flush” (once a day) as dictated by the local and/or remote supervisory. RO membrane Fresh Water Flush will be implemented through actuation of the RO feed pump (P 02) and use of a three-way valve (AV 01) to direct the product water flow from the product water storage tank (T-2) directly to the RO membrane module. Furthermore, in the event of high scale accumulation on the RO membrane, a compact antiscalant (R-1, optional) reservoir and metering pump (MP 01) are controlled by the local and/or remote supervisory to discharge a suitable acid/antiscalant dose to negate previously mentioned scale accumulation.

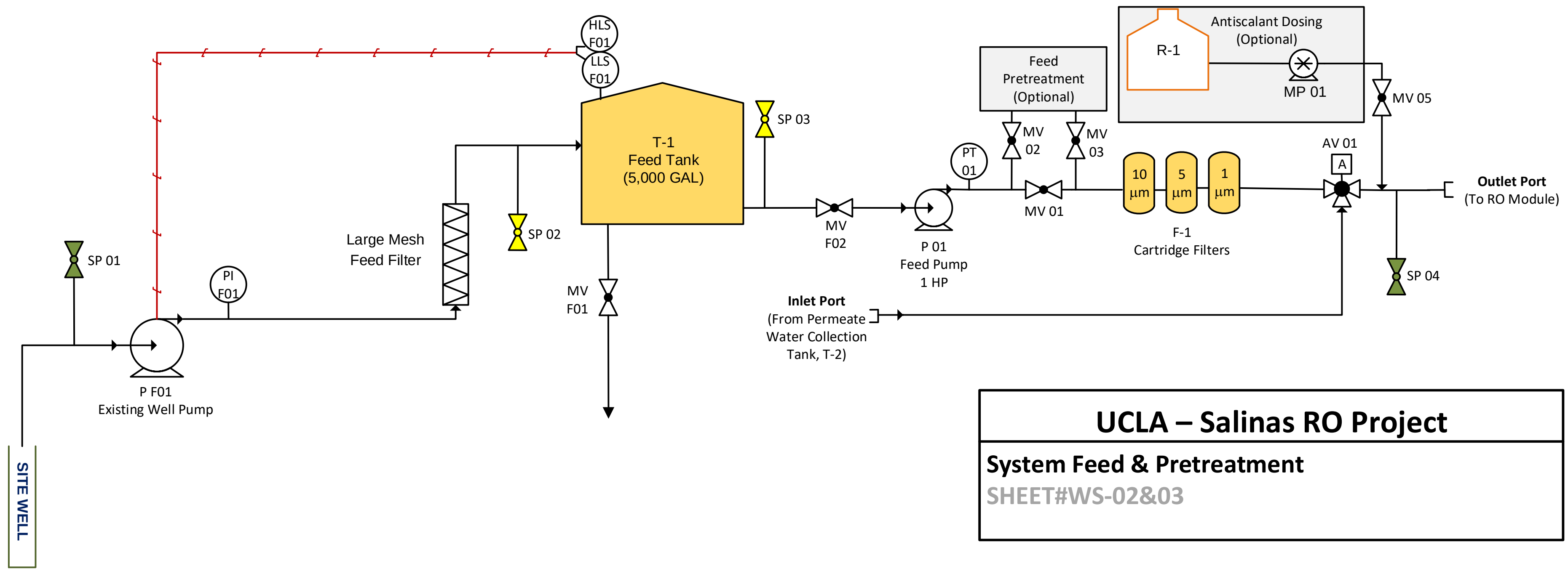

Figure 4-2A: Feed & Pretreatment System section Process Flow Diagram (WS-02&03, Worksheet-02&03) for the remote communities study.

4.2.2 RO Module Process Flow Diagram (PFD)

The flow to the RO unit (**Fig. 4-2B**) will be dictated by a Variable Frequency Drive (VFD 01) RO pump (P 02) under the action of the onsite control system that will ensure operational guidelines and community requirements are met. Before entering the RO, an antiscalant (AS) dosing port is to be placed after the three-way valve where an optional AS dosing reservoir (R-1) will supply a predetermined AS dose to the RO feed system through a metering pump (MP 01). The AS will serve as a backup option for reducing scale build-up on RO membranes surface if the previously mentioned fresh water flush is determined to be insufficient for restoring membrane permeability, and the saturation levels of sparingly soluble mineral salts (e.g. calcium carbonate and calcium sulfate) in the feed are exceeded. Furthermore, antiscalant dosing will shutoff upon reaching desired saturation levels, upon RO system shutdown, and upon triggering AS metering pump high-level concentration setpoint sampled at the feed. Multiple sensors/transmitters (pressure, conductivity, flow) are present prior to the VFD RO pump (P 02) which will relay important feed parameters (pressure, conductivity, and flow) to the online monitoring system.

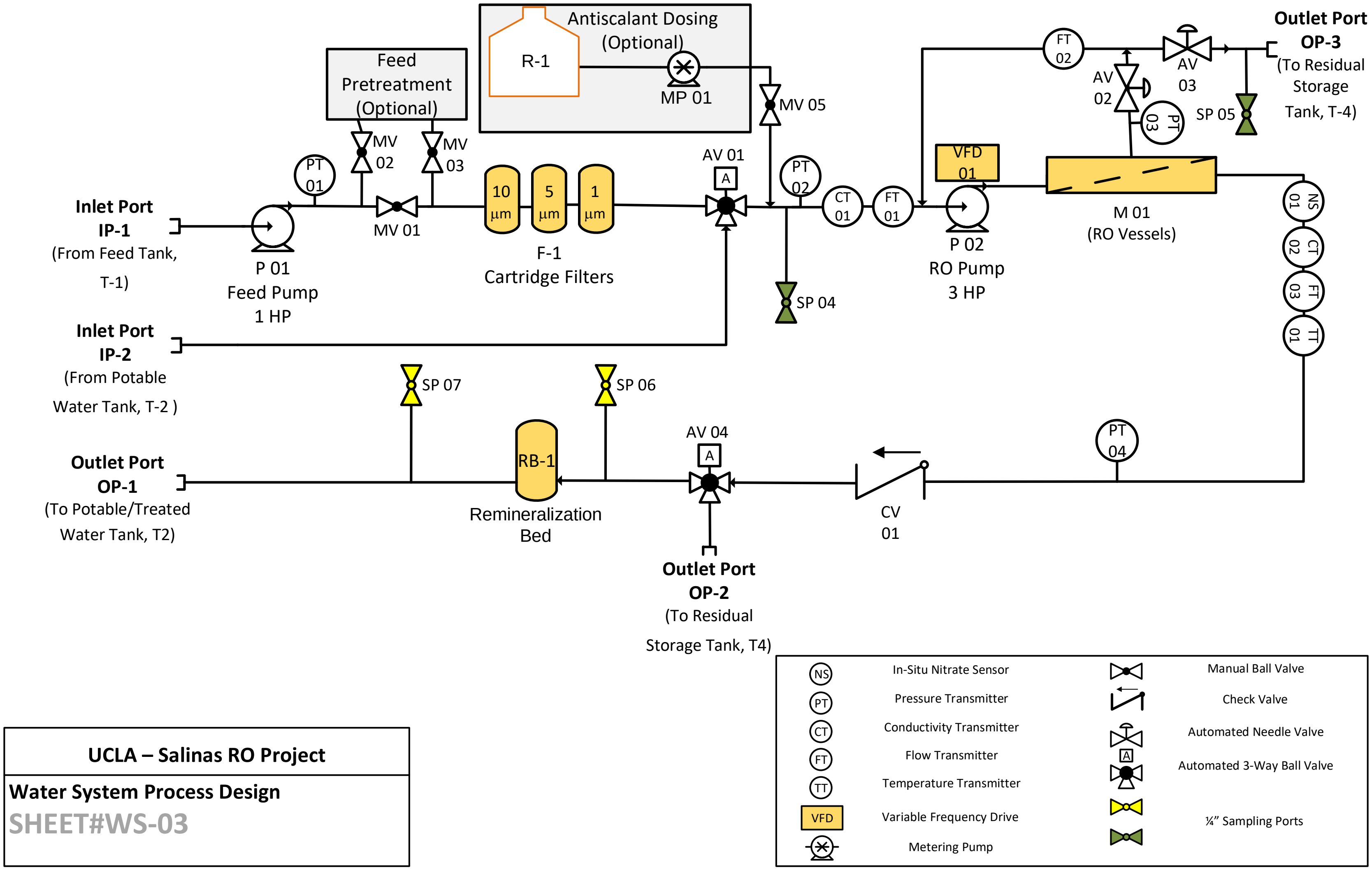

Figure 4-2B: Pretreatment & RO System section Process Flow Diagram (WS-03, Worksheet-03) for the remote communities project.

Upon entering the RO module, community brackish water will be treated under high recovery (90%) where the concentrate will be pass through a depressurizing automated needle valve (AV 02) that will recalibrate the recycle stream's pressure to the same level as that of the stream prior to entering the VFD RO pump (P 02). The now depressurized concentrate stream will enter a split where it will be partially redirected back to the RO feed at a recycle flow rate within the design parameters to achieve desired recovery, and the remaining concentrate flow will be depressurized to atmospheric conditions for residual tank (T-4) storage at Outlet Port OP-3. It is noted that another pressure transmitter is present at the concentrate outlet of the RO unit to be recorded locally and transmitted to a remote supervisory server at UCLA WaTeR Center.

The RO permeate line has multiple water quality sensors/transmitters that will record and report the quality of permeate stream. Nitrate sensor (NS 01), conductivity transmitter (CT 02), flow transmitter (FT 03), temperature transmitter (TT 01), and pressure transmitter (PT 04) will ensure that nitrate concentration (mg/L as NO3-), TDS (mg/L), flow (GPD or GPM), temperature (F), and pressure (PSI) levels are within design and regulatory guidelines. The permeate stream nitrate sensor (NS 01) is an online spectroscopic sensor that will report nitrate data in the permeate during commissioning which will allow us to calculate nitrate passage and corollate it to salt passage (from conductivity correlation) in order to eliminate the continuous use of said nitrate sensor which will extend the component's life cycle. The permeate stream continues until reaching a remotely-controlled three-way automated valve (AV 04) that regulates whether the permeate will flow to remineralization bed (RB-1) and post-treatment, or to the residual storage tank depending on the desired mode of operation. A check valve (CV 01) is installed prior to the three-way valve (AV 04) to ensure no backflow into the RO is possible from either outlet.

4.2.3 RO Product Post-Treatment

The system design strategy in regard to the permeate post-treatment section (shown in **Figure 4-2C**) is a to provide the treatment system with post-treatment that allows for permeate mineral balancing and pH stabilization, as well as guarantees safe potable water delivery to the community through disinfectant-dosing when needed. The need for pH adjustment and mineralization is a result of RO ion separation from the solution; where the lack of ions reduces the alkalinity of the permeate (and pH reduction to around 6.5) which leads to potential metal-pipe leaching into the permeate during distribution if left unattended. In addition, ultra-pure permeate has been known to leave a strange taste due to its relatively high acidity that leads it to form carbolic acids upon reacting with the atmosphere. Furthermore, provision in the system (i.e. with needed connections as in the case for the green sand filter connection in the pretreatment section) are added for the installation of a disinfection system that consists of a chlorine reservoir (R-2), and a chlorine metering pump (MP 02).

The adjustment of the product water pH and mineral composition is done through the utilization of a remineralization bed (specifically a limestone contractor, RB-1). The alkalization/remineralization limestone bed was used due to its commercial availability, its ease of installation, and most importantly its ability to address both the need for increasing alkalinity and remineralizing the permeate at the same time in comparison to other technologies of interest [40]. The benefits of using a calcium carbonate ($CaCO_3$) in the form of limestone pellets in a bed contractor are: the simple dissolution of calcium and carbonate into the permeate and providing apt remineralization; limestone dissolution simultaneously increase alkalinity, calcium hardness and pH in RO permeate, as well as decreasing the product water corrosivity; its non-hazardous material and operation that can be done autonomously from human contact and would only need replacement of the bed once its been consumed; the low capital cost and maintenance cost in comparison to liquid chemical addition (base) [67]. It is noted that alkalinity values of less than 40 mg/L as $CaCO_3$ in the RO permeate would have to be treated through a limestone bed until passing the water quality alkalinity criteria of 40 mg/L as $CaCO_3$ [19].

Disinfection of the product water is warranted if any microbial contamination is detected through sampling the distribution system or the potable water tank (T-2). Upon detection, a chemical storage tank (R-2) will be filled with chlorine disinfectant (Cl_2) in order to eliminate any microbial presence in the distribution network. The injection of chlorine into the distribution system is done through a metering pump (MP 02) into the product water directed into the pressure tank (T-3). The metering pump will be interlocked with the pressure tank feed pump (P D01) in order to provide a consistent feed flow rate in proportion to the water flow under all operating conditions. The presence of disinfectant in the system is aimed to provide the commonly recommended chlorine residual level of 0.4-0.6 mg/L near the injection point [68, 69].

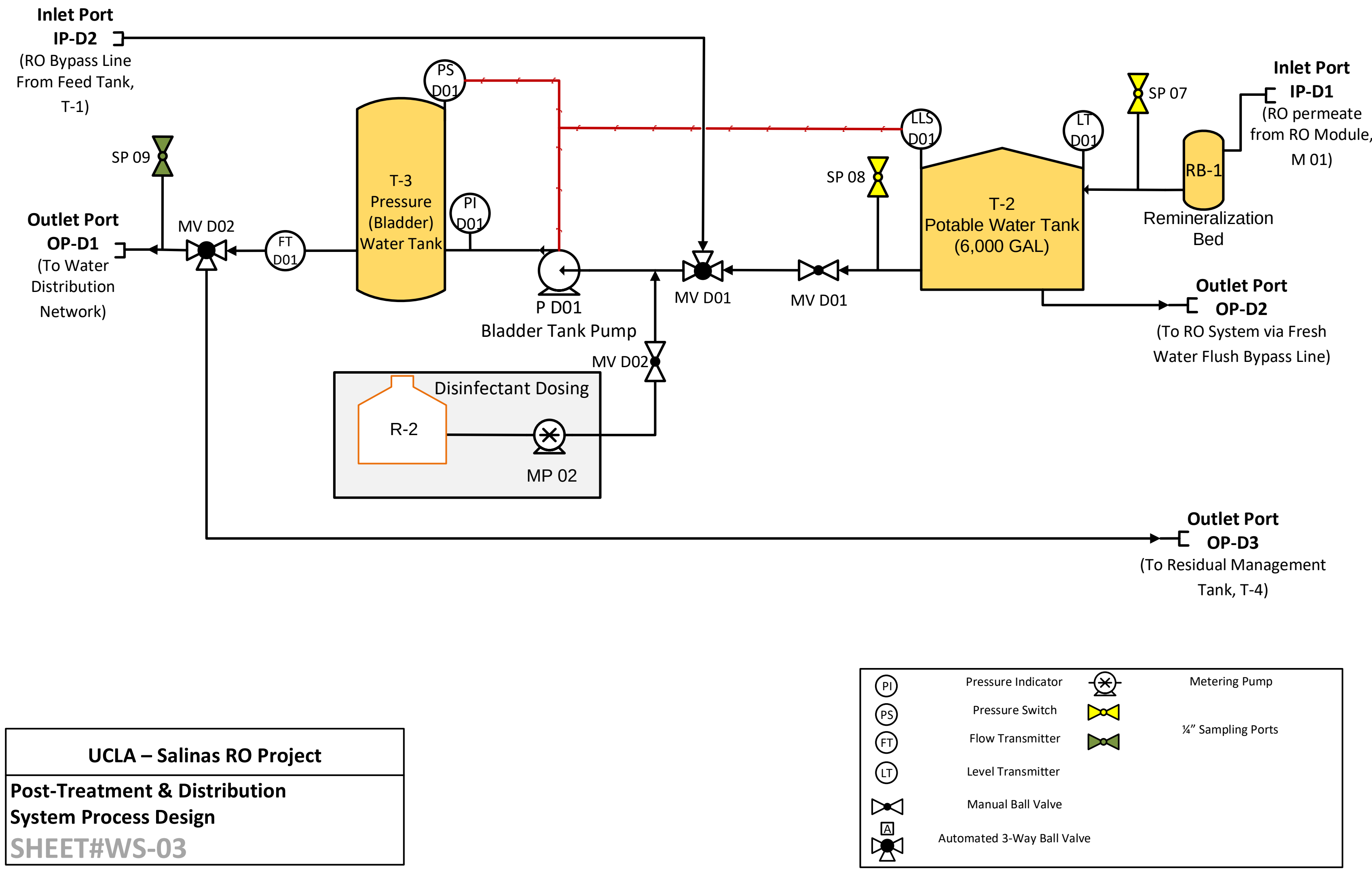

Figure 4-2C: Post-treatment & Distribution section Process Flow Diagram (WS-03, Worksheet-03) for the remote communities project.

4.3 Analysis of RO Module Process Design

In continuation to the optimization the DAC RO treatment system, an analysis of the RO module process design is conducted. The module process design analysis begins with an analysis of partial concentrate recycle in terms of meeting community septic system capacity, and financial limitations. The RO module design continues into the choice of element size suitable for treatment is analyzed on the basis of meeting design production capacity in comparison to other commercially available elements. In addition, the determinization of said element operation is achieved through optimizing the configuration and number of elements in operation in regard to meeting previously mentioned process specifications (**§4.1**). Furthermore, the need for second pass operation is evaluated in the case that permeate quality limit (25 mg/L as NO_3^-) proves to be difficult to meet through the designed RO single-pass treatment due to elevated feed concentrations. And finally, the need for nitrate monitoring is assessed through the utilization of commercially available, and financially viable, permeate conductivity transmitters as surrogates for salt-nitrate correlation in the permeate.

4.3.1 Evaluation of Partial Concentrate Recycle to Achieve High Recovery

Partial concentrate recycle via single module operation was chosen as the design basis for high recovery operation on the study DACs due to its small footprint in regard to community system discharge, and due to its compactness in size and low capital cost in comparison to commercially available high recovery options. High recovery operation in study DACs has been established as a design necessity in previous sections (**§3.1.2, §4.1.3**) in order to address the community septic tank's limited capacity (volume) summarized in **Table 3-1B** (**§3.1.3**), where a design objective was to reduce the amount of RO discharge into said septic tanks to minimize nitrate loading into the leach fields. **Figure 4-3A** summarizes the volume of waste generated with respect to the operational recovery for each study DAC at their respected design flowrates.

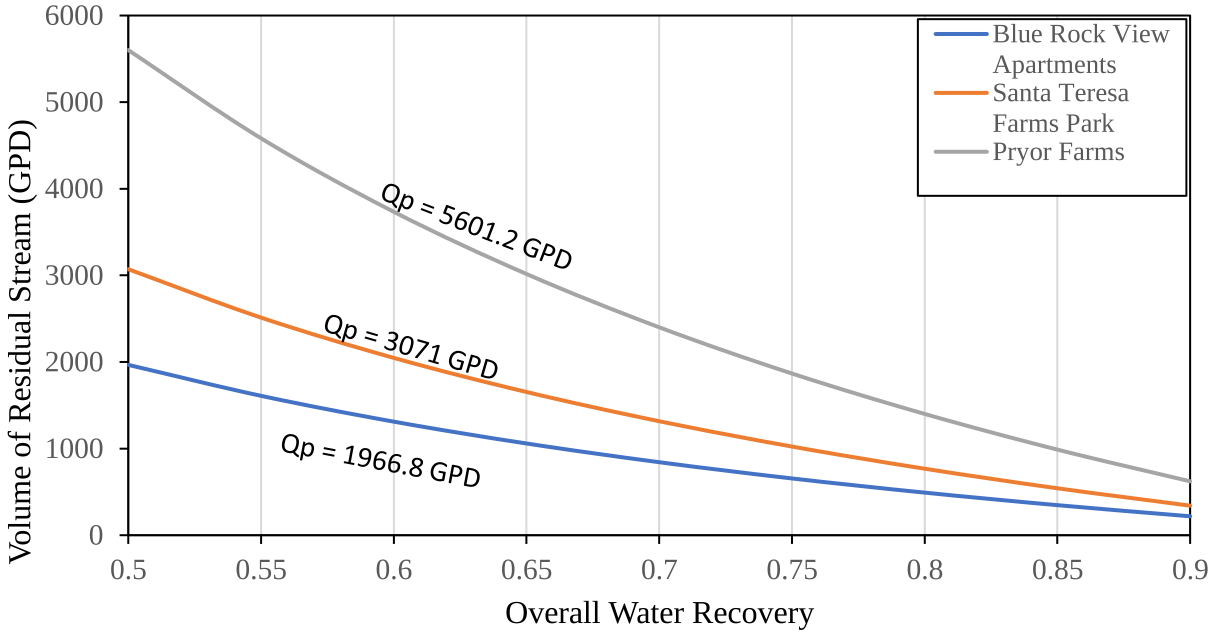

Figure 4-3A: Volume of residual stream generated at different levels of product water recovery for production of drinking water at the design production capacity, Q_p, at each study DAC.

High recovery operation (higher than 50%) can be achieved through numerous system configurations, but most notably through utilizing systems that have multiple stages in the series configuration (**Fig. 2-2**); or through one-module systems (**Fig. 2-4**) that utilize concentrate recycling and multi-element operation in series. Multi-stage RO operation is able to achieve the targeted high recovery of 90% through utilizing multiple pressure vessels in series that the feed passes through until it exits the system and is discharged as concentrate. Each stage consists of parallel RO modules that contain multiple pressure vessels in series, where a single pressure vessel contains up to 6-element in series (in the case of brackish water) [51]. The number of stages in series dictates the extent of recovery desired, therefore the number of stages is a function of the overall system recover (Y). **Table 2-2A** (**§3.1.3**) shows that in order to reach both the design goal of high recovery operation and design objective of minimal RO discharge into the septic tank; the multi-stage RO system would have to employ a total of 3 stages containing 6 pressure vessels each. 18 pressure vessels containing 1-8 elements each would cause both an overproduction dilemma that the community would not be able to mitigate, as well as an inflation in capital cost (and utility cost) for such limited usability (community potable water production). It is important to note that large scale installment of multiple RO modules would require additional efforts in infrastructure development that may surpass the viable on-site treatment space allowed within the confines of the community.

Employing singe-module with partial concentrate recycle, on the other hand, has the customization ability to meet both the community potable water needs and septic tank limitation, as well as present an optimal capital cost for small communities ($50,000-$80,000) [40]. The single-module RO system would also be stored in a small 10' x 10' shed with a concrete slab, or a 20' x 20' x 8' metal container; posing little to no inconvenience to the community.

High recovery in single-module systems can be achieved through employing a recycle stream operating at a design recycle ratio ($R_{Ratio} = Q_R/Q_o$). The module consists of a pressure vessel with up to eight membrane elements connected in series [51]. The concentrate of the first element becomes the feed to the second, and so on. The module's product port collects the permeate from all the elements' product tubes continuously through RO operation. The RO concentrate leaves the RO concentrate outlet port at essentially the feed pressure, controlled by the concentrate pressure regulator valve. Part of the concentrate stream resulting from RO separation is recycled and added to the suction side of the high-pressure RO pump at the indicated mixing point (MP) on **Fig. 2-4** which increases the feed flow to the module, and achieve recommended single-pass recovery (Y_{SP}) [51].

Singe-module operation through partial concentrate recycle can be utilized in reaching the high recovery of interest (90%) through essentially varying the recycle ratio and the number of elements depending on the targeted specifications. The range of flexibility in terms of varying the recycle ratio and the single-pass recovery (essentially the number of elements employed) in achieving high recovery operation is summarized in **Fig. 4-3B.**

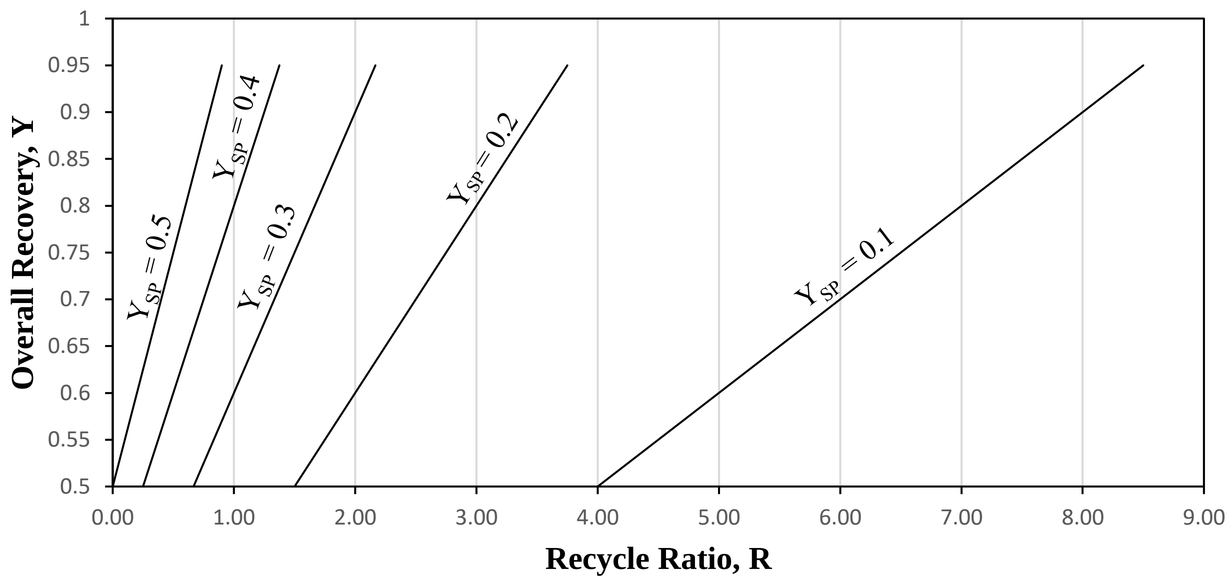

Figure 4-2B: The flexibility of overall operational recovery (Y) as a function of the recycle ratio (R) for choice single-pass recovery (Y_{SP}) values applicable to the Single-Module Partial Concentrate Recycle model adapted for this study.

The single-pass recovery and the number of elements optimization is discussed thoroughly in **§4.4.3**; *Determination of RO Elements Configuration to Meet Process Specifications*, as they are interchangeable functions of each other, and of desired range of production per study community.

4.3.2 Selection of RO Element Size to Meet Production Capacity

The RO element size selection method is based on a specified range of production that covers the design flow rate for routine operation, as well as covers the design range of production in the case of increased community demand (Maximum Daily Demand) for each study community (**Table 4-3A**). The design production capacity is to be operated up to the maximum recovery limit per element value of 20% (**Eq. 4-2**). Given that the source water to be treated is brackish/well water which would be operated at the above-mentioned specifications in terms of production range and element recover; a commercially available 4" diameter element (RE-4040BE) was chosen to be the design membrane of operation.

Table 4-3A: The desired design range of production (GPD) and the design permeate flowrate (GPD) for the study DACs

	Study DAC		
	Bluerock View Apartments	Santa Teresa Farms Park	Pryor Farms
Range of production (GPD)	1,900 - 4,200	2,700 - 4,100	5,450 - 5,800
Design production capacity (GPD)	1,966.80	3,071	5,601.20

The element size dictates the operational production capacity of the RO system (product and discharge), the quality of the product produced, and the frequency of membrane cleaning to reduce fouling. **Table 4-3B** indicate the choices of commercially available membranes for RO high recovery operation [51].

Table 4-3B: A summary of comparisons of three element size operation in well water conditions with regards to their feasible operational flowrates[51].

Feed Source		Well Water/Softened Water
Max recovery per element (%)		20
Max. permeate flowrate per element (GPD)	2.5" Diameter	710
	4" Diameter	2,100
	8" Diameter	7,400
Max. Feed flowrate per element (GPD)	2.5" Diameter	8,200
	4" Diameter	25,920
	8" Diameter	89,280
Max. Concentrate flowrate per element (GPD)	2.5" Diameter	1,440
	4" Diameter	5760
	8" Diameter	22400

From the above table, it is found that a 4” element is optimal for the range of production intended in this study with a maximum permeate flowrate per element of 2,100 GPD. It was found (**§4.4.3)** that operating 2 to 4 4” elements in within the design specifications would feasibly produce the desired production capacity, whereas it is infeasible to operate a 2.5” in a single array operation; where it would require two-array operation to meet the upper limit of the production capacity of 5,800 GPD, with a total number of 16 elements in series. The opposite is true with the larger-diameter 8” element where the production capability of said element exceeds the community demand and would violate the goal and objectives of the design, even with single element operation.

In regard to operating the element within the flux specifications of the design (12-17 gfd) the only feasible membrane surface area for the desired production range can be found in both the 4” and 2.5” elements. For the 2.5” element, even with disregarding the increased capital and utility costs associated with inflated number of elements in multi-array operation; the large flux value facing the first element in operation would increase concentration polarization and the susceptibility for scaling to the point of requiring a large frequency of chemical cleaning (antiscalant) that the design is clearly trying to minimize. Whereas in regard to the larger element of concern (8"), the low flux operation associated with operating within the production range would be inconsistent with the flux range previously specified; resulting in lower-quality permeate.

4.3.3 Determination of RO Elements Configuration to Meet Process Specifications

The determination of the number of elements in series to be used for each site module was done through initially setting the range of production (GPD) for each study DAC. Given that the communities have fluctuations in their water consumption trends; a range of production capacities was covered (±250 GPD from the design production flow for each site, or double the maximum daily demand) that will meet community demand throughout the year, particularly during the months of May-August which portray the maximum daily demand (reported in **Table 4-1C)**. Upon setting the range of production, it is integral to operate within the flux ranges of 12-18 gfd as not following the flux range (overfluxing/underfluxing) results in multiple problems such as low-quality permeate (high nitrate concentration), increased surface scaling, decrease in element lifespan, etc. The total single pass recovery is then calculated (**Eq. 4-2**) given an overall recovery, Y, of *90%* and the reported recycle ratios in **Table 4-1C**.

Overall Recovery, $Y = Y_{SP} (1 + R_{Ratio})$ (Eq. 4-2)

Upon finding the single pass recovery, Y_{SP}, the number of elements is then found by rearranging **Eq. 4-2**, and setting the maximum element recovery, Y_i, at 20%:

Average element recovery, $Y_i = 1 - (1 - Y_{SP})^{\frac{1}{n}}$ (Eq. 4-3)

Both the average element recovery and the total number of elements, n, were optimized using RO System Design Software (CSMPro5) to cover the initially stated range of operational production capacities through flux range consistency assurance and permeate quality simulations monitoring.

Table 4-3C: DAC site-specific projected range of production at 90% recovery based on number of elements in series employed.

	Study DAC, Number of Elements			
	Bluerock, **2E**	Bluerock, **3E**	Santa Teresa, **3E**	Pryor Farms, **4E**
Range of production* (GPD)	1,900 - 2,400	2,400 - 4,200	2,700 - 4,100	5,450 - 5,800
Range of operational flux** (gfd)	11.18 - 14.12	9.41 - 16.47	10.59 - 16.08	15.74 - 17.06
Total single-pass recovery (%)	29.5 - 34.4	34.4 - 46.7	36.9 - 46.2	55.3 - 56.7
Element recovery at the upper limit(***) (%)	19	18.9	18.7	18.9

(*)Design production capacity is 1,966.8, 3,071, and 5,601.2 GPD for Bluerock, Santa Teresa, and Pryor Farms respectively; (**) membrane used: RE-4040BE with SA of 85 ft2; (***) Average element recovery is optimized using CSMPro5.

Most study DACs (with the exception of Bluerock View) site module configurations would require a constant number of RO elements throughout the period of operation to adhere to the specified range of production, and the process specifications mentioned in **Tables 4-1B** and **4-1C**. In the event where the site-specific design flow is shown to be at operation near the element recovery limit of 20%; the RO module configuration is to add another pressure vessel for an extra single element in series so that an increase in flow is enabled when needed, without surpassing the element recovery limit which increases concentration polarization (C.P.) and therefore the chance of element scaling. In the case of Bluerock View, it is projected that operating the design flowrate should be manageable by the RO module throughout the periods of operation. However, in the event of increased potable water consumption (such as the case with reported Maximum Daily Demand values) where the community would require operating the RO at double the current capacity; the Bluerock RO module would have to result to 3 elements-in-series operation through the employment of an extra pressure vessel containing said third element.

4.3.4 Evaluation of the Need to Integrate Second-Pass Operation

In the cases of which a study site is presented to the supervisory monitoring operator with a large spike of nitrate contamination in their source water wells (such as the case in Pryor Farms Well "L") that the community is unable to mitigate with the design RO setup, or is unable to redirect the feed of the RO system towards another well that's within the proximity; a second-pass RO configuration is to be implemented to optimize the overall nitrate rejection and therefore the quality of the permeate.

Upon conducting a mass balance calculation based on the given feed nitrate concentration of 389 mg/L as Nitrate, the design operation flowrates, and the two observed membrane rejection values of 98% and 96% (reportingly CSMPro5 simulation nitrate rejection value and element technical manual-reported nitrate rejection value); it was found that the permeate nitrate concentration from single-pass operation would exceed the design-specified (**Table 4-1C**) permeate nitrate concentration limit of 25 mg/L as NO_3^-. It was confirmed through using CSMPro5 that the permeate water quality of a single-pass operation at that well (well "L") would also be less than the targeted nitrate permeate concentration limit (safe point) of 25 mg/L as NO_3^-. Therefore, a second-pass option for nitrate removal in Pryor Farms well "L" was designed to produce potable water with permeate quality less than the limit mentioned above. **Table 4-3D** correlates to the design specifications set for 2nd pass operation according to the methodology discussed in the previous sections of this chapter.

Table 4-3D: Overall specification ranges and limits for Two-Pass RO System for Nitrate Removal and Salinity Reduction for DACs that experience elevated spikes in their feed water nitrate concentration.

Two-Pass RO System Specification	**Desired Range for RO System Specification**
Feasible range of production (GPD)	5,000 - 5,800
1st pass recovery (%)	90
2nd pass recovery (%)	50
Overall recovery (%)	> 85%
Flux (gfd)	13 - 17
Number of elements in 1st pass	6
Number of elements in 2nd pass	4
Cross-flow velocity range (m/s)	0 - 0.57
Single element recovery (%)	15 - 20
Permeate nitrate concentration limit (mg/L as ion)	25
Permeate TDS concentration limit (mg/L)	150
Maximum operating pressure per module (PSI)	350

A second-pass configuration would require a second RO module with its own high pressure VFD pump, as well as an increase in the total number of elements used as illustrated in **Fig 4-3C**. The 2nd RO module's feed stream consists of half the amount of the 1st pass' permeate, where the remaining half of the 1st pass permeate is blended with the permeate resulting from the 2nd pass. The blending of the permeate streams of the two passes poses to increase the mineral composition of the final product water to reduce the extent of remineralization followed downstream. It is important to note that since the 2nd pass feed consists of the 1st pass permeate; there would be no need of disposing of concentrate, as working 50% 2nd pass recovery poses to only double the concentration of the 1st pass low salinity permeate. Instead, the concentrate is redirected towards the feed of the 1st pass (before the VFD pump, P 02) to blend with the higher salinity source water feed. as a result, the only residual management required for the Two-Pass configuration would be for the 1st pass (operating at 90%) retentate which has a flowrate equal to 10% of the feed flowrate.

It is important to note that since the elevated nitrate concentrations were discovered in the Pryor Farms community well; the RO system integration was relocated to operate at on-site well displaying reduced levels of nitrate (101.7 mg/L as NO_3^-), well “6”, in order to optimize the capital and operation cost associated with said integration and operation of the community RO system.

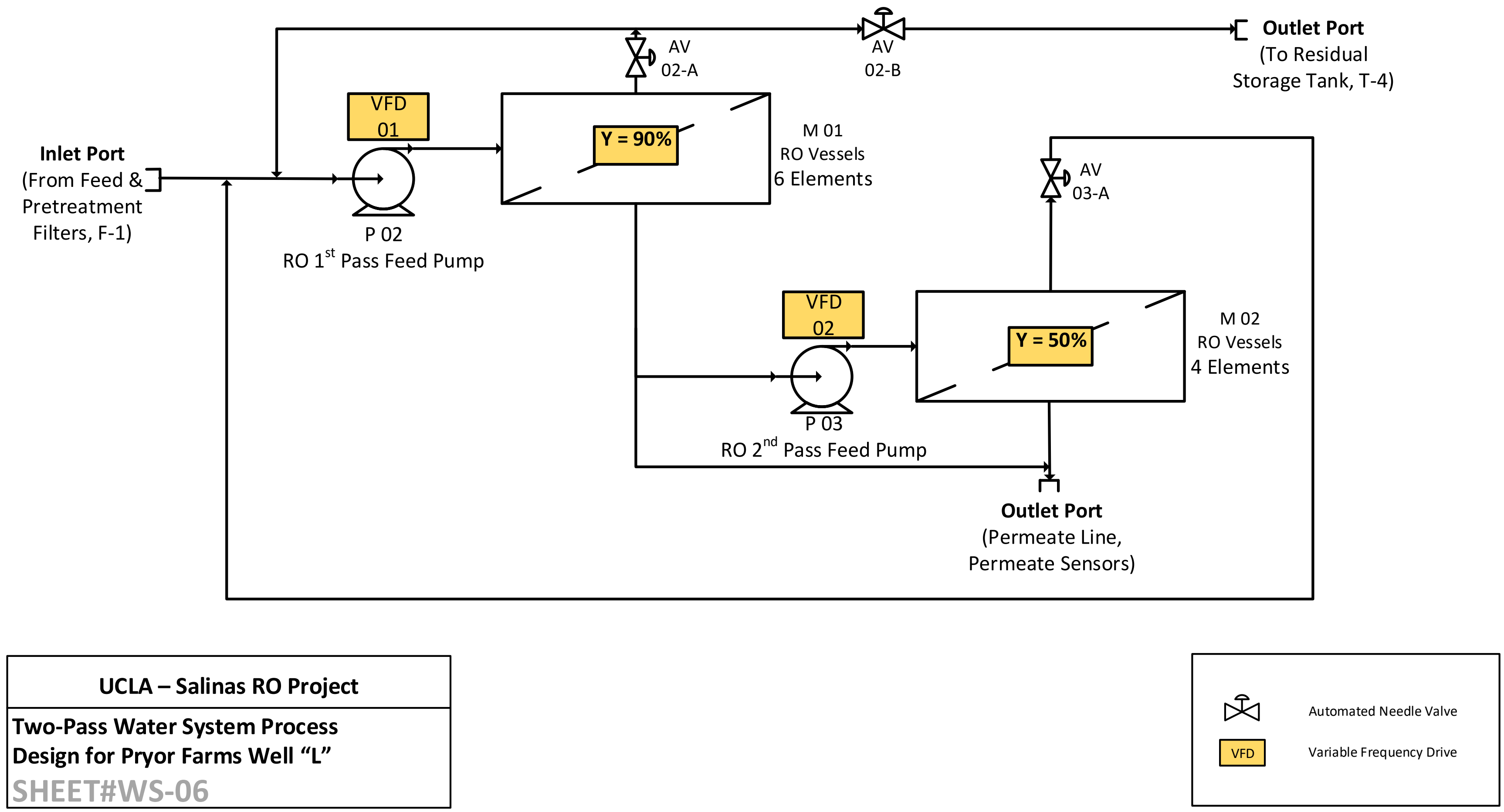

Figure 4-3C: Two-pass configuration Process Flow Diagram (PFD) for partial-recycle high recovery RO water treatment system option for consideration at communities that exhibit elevated spikes of nitrate concentration in their well water feed source.

4.3.5 An Assessment of Use of Permeate Conductivity as a Surrogate for Nitrate Concentration

Nitrate concentration monitoring in the RO permeate stream is a design objective of this study in order to maintain safe community drinking water standards throughout RO system operation. Conventionally, nitrate monitoring is done through either periodic sampling of the product, or through installing an in-line nitrate concentration transmitter/sensor. Given the remote location of the study communities; periodic sampling of the product is deemed infeasible due to the lack of on-site and nearby technical support. Nitrate sensors on the other hand are proven to be costly to purchase and maintain/replace ($800 minimum per sensor) [70]. As a result of the above, it was hypothesized that financially-feasible conductivity transmitters/sensors [71] can be utilized as a surrogate for nitrate concentration measurement through the establishment of salt-nitrate concentration correlation in the permeate.

The approach of devising a relationship between salt and nitrate concentrations in the permeate is initiated through the establishment of a site-specific CSMPro5 (OLI-reconciled) salt passage-nitrate passage correlation for all sites to include multiple operational recoveries (50%, 70%, and 90%), with each recovery setting covering an operational flux range of 10-15 gfd and three different nitrate feed concentrations. The resulting salt passage-nitrate passage correlation is estimated to cover the possible operating conditions at each site, with the assumption that site water salinity profile (with the exception of nitrate) remains unchanged.

Table 4-3E: The design range of specifications in terms of conducting the multi-recovery, multi-flux, and multi-nitrate concentration salt passage-nitrate passage correlation simulations using CSMpro5.

Recovery range of operation (%)		50, 70, 90	
Flux range (gfd)		10 to 15	
		Study DAC	
	Bluerock View	*Santa Teresa Park*	*Pryor Farms*
Simulated feed nitrate concentration range (mg/L as NO_3^-)	100, 180, 260	20, 60, 100	100, 200, 400
Current feed nitrate concertation (mg/L as NO_3^-)	121.95 - 182.7	45 - 46	101.7 (389*)

(*) corresponds to the previous intended well of operation at Pryor Farms, well "L", which has been since replaced by nearby on-site well "6" due to its stable nitrate concentration profile and lower feed nitrate concentration of 101.7 mg/L as NO_3^-.

Said correlation can be used in estimating the nitrate concentration at the permeate side from evaluating the corresponding TDS value at said stream. Site-specific TDS values can correspond to a certain conductivity (mS/cm), depending the DAC water profile, through establishing a site-specific conductivity-TDS correlation at an increasing range of concentrations with OLI Studio. The conductivity-TDS relationship could be implemented in future RO treatment integration into community source wells to indicate the TDS value of the permeate side given a certain conductivity reading (mS/cm), which in its turn can be used in estimating the approximate nitrate concentration in said stream; leading to minimizing the use of the on-stream nitrate sensor.

Chapter 5

5. Results & Discussion

This chapter details the simulation results for the RO system based on declared design range of operation (**§5.1**), analysis results of operational element number variation (Bluerock View) in RO operation (**§5.2**), the results of evaluating the allowable feed nitrate concentration until reaching the EPA MCL of 45 mg/L as NO_3^- and the element "safe point" limit until reaching the nitrate permeate concentration limit of 25 mg/L as NO_3^- (**§5.3**), the simulation results of the two-pass RO module configuration (Pryor Farms Well "L") (**§5.4**), and finally, the correlation of nitrate passage with respect to salt passage covering multiple operational recoveries, fluxes, and feed nitrate concentrations at each DAC site (**§5.5**).

The procedure for conducting CSMPro5 simulations, with OLI Studio Reconciliation, is summarized in **Appendix C**, and a fundamental Mass Balance analysis to determine the feasibility and accuracy of the simulation results is attached in **Appendix G**.

5.1 RO System Simulation Results Based on Design Range of Operation

The determination of the RO treatment system performance was conducted through the use of RO System Design Simulations done via CSMPro5 and reconciled with OLI Studio. The simulation guidelines were set within the range of specifications mentioned in **Tables 4-1B & 4-1C** in order to determine the design feasibility of implementing RO treatment modules in the three study DAC communities (Bluerock View Apartments, Santa Teresa Park, and Pryor Farms). **Table 5-1A** summarizes the range of results of the simulations conducted at the previously mentioned range of specifications for each site.

Table 5-1A: Simulation results summary for the three study DACs of concern based on the design range of specifications.

	Study DAC			
	Bluerock View	Santa Teresa Park	Pryor Farms (Well 6)*	Pryor Farms (Well L)
Feed flowrate (GPD)	2111.1 - 4666.7	3000.0 - 4555.6	5944.4 - 6444.4	5944.4 - 6444.4
Number of elements in series	2 - 3	3	4	4
Permeate flowrate (GPD)	1900.0 - 4200.0	2700.0 - 4100.0	5350.0 - 5800.0	5350.0 - 5800.0
Concentrate flowrate (GPD)	211.1 - 466.7	300.0 - 455.6	594.4 - 644.4	594.4 - 644.4
Permeate flux (gfd)	11.18 - 16.47	10.59 - 16.08	15.74 - 17.06	15.74 - 17.06
Recovery (%)	90	90	90	90
Recycle Ratio	2.05 - 0.93	1.44 - 0.95	0.73 - 0.67	0.73 - 0.67
Cross-flow velocity (m/s)	0.13 - 0.28	0.18 - 0.28	0.36 - 0.39	0.36 - 0.39
Average single-pass recovery	15.15	13.84	13.24	13.24
Feed salt concentration (mg/L)	1446.27	561.09	1257	1618.85
Feed nitrate concentration (mg/L as NO_3^-)	180	45	101.7	389.7
Permeate salt concentration (mg/L)	118.18 - 71.06	45.38 - 27.92	53.62 - 48.83	81.56 - 73.90
Permeate nitrate concentration (mg/L as NO_3^-)	27.02 - 16.03	6.69 - 4.06	8.61 - 7.78	33.18 - 30.09
Intrinsic salt rejection (%)	91.83 - 95.09	91.91 - 95.02	95.73 - 96.15	94.96 - 95.44
Intrinsic nitrate rejection (%)	85.00 - 91.09	85.13 - 90.98	91.48 - 92.30	91.49 - 92.28
Permeate pH	6.43 - 6.21	6.51 - 6.30	6.19 - 6.15	6.19 - 6.15
Feed pressure (PSIG)	201.71 – 239.9	128.9 - 153.0	190.2 - 195.0	219.4 - 223.4
Concentrate pressure (PSIG)	199.2 – 238.2	126.2 - 149.7	185.0 - 189.4	214.3 - 218.0

* Well 6 is the new designated well of operation in Pryor Farms due to the elevated levels of nitrate (389.7 mg/L as NO_3^-) in the old source water well (Well "L").

The range of permeate flowrates for each study site covers both the design flow rate (**Eq. 4-1**) and the maximum daily demand (**Table 4-1C**), while producing a permeate with nitrate concentration of approximately equal to or less than 25 mg/L as NO_3^- with respect to all designated source wells of operation. In the case of Bluerock View operating at the lower limit of the range of investigated permeate flowrates (19000 GPD); the nitrate concentration in the permeate exceeds the specified "safe point" limit of 25 mg/L as NO_3^- by a small margin. However, given that the flux value at said lower limit does not fall within the recommended range of operational flux values of 12-17 gfd; flowrates that fall below the specified range of flux will not be operated. In the case of which the flowrate falls below said range of flux; the permeate flowrate will be increased until it falls within the specified flux range, as well as produces a permeate nitrate concentration below the "safe point" limit of 25 mg/L as NO_3^-. This approach results in lowering the time of operation for the RO until reaching the desired volume of potable water produced, in increasing the quality of the permeate due to the relatively stable salt rejection of the membrane with respect to the rapid increase in permeate flow, as well as in reducing the possibility of scaling associated with operating outside the recommended flux range. **Figure 5-1A** illustrates the simulated nitrate permeate concentration as a function of operable permeate fluxes for the study DACs of concern in their design element configuration with the exception of Bluerock View, which the design configuration of 2E does not entirely cover the recommended range of flux (12-17) as it can only achieve a flux value of ~ 14 gfd before reaching the recommended single element recovery limit of 20%. Further operation at that configuration (2E) beyond the recommended single element recovery limit will result in elevated scaling potential. A comparison between the two Bluerock operational element configurations

(2E & 3E) will be discussed thoroughly in the next section (**§5.2**). Simulation generated data corresponding to **Fig. 5-1A** is attached in **Appendix D**.

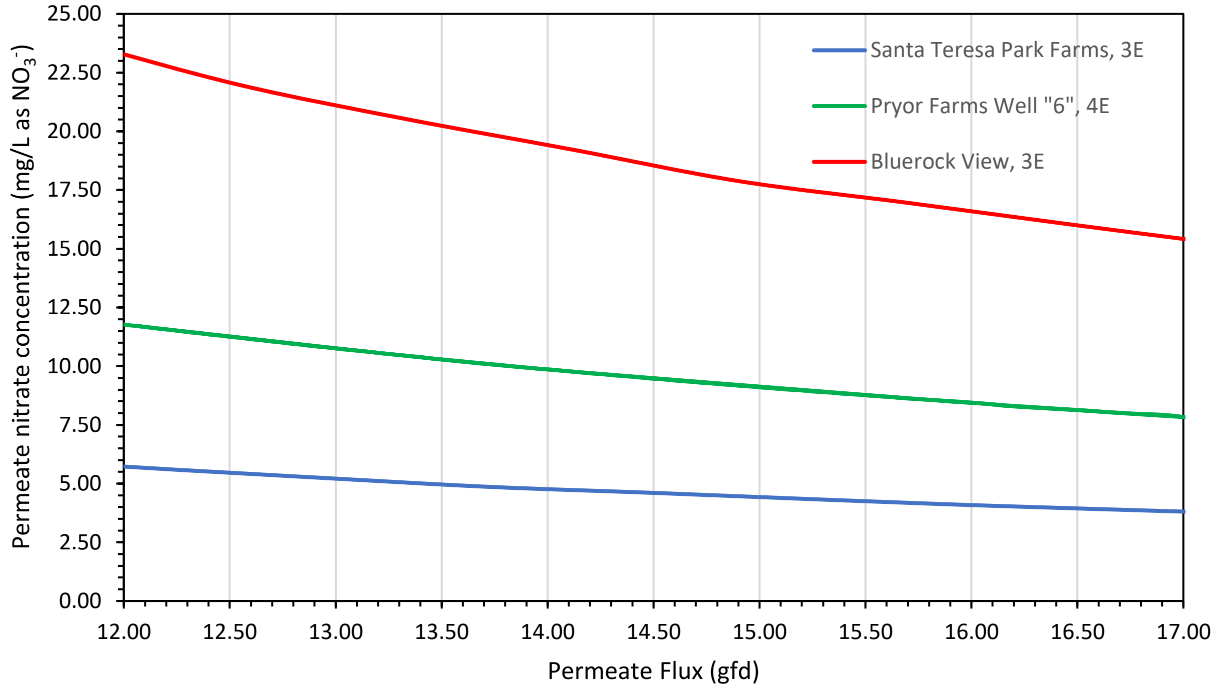

Figure 5-1A: simulated nitrate permeate concentration as a function of operable permeate fluxes for the study DACs of concern.

Furthermore, the resulting cross-flow velocity from evaluating the feed flow contacting the CSM RE4040-BE membrane was found to fall within the previously specified (**Table 4-1B**) range of 0.00 – 0.57 m/s, as the values were found to fall between 0.13-0.28, 0.18-0.28, 0.36-0.39 m/s for Bluerock, Santa Teresa, and Pryor Farms respectively. The permeate pH falls slightly below the lower limit of the allowable range of pH set by the EPA (6.5-8.5), therefore; remineralization is justified and warranted to avoid metal leaching from distribution system piping. The range of operational feed and concentrate pressures were found to fall below the maximum specified operating pressure of 300 PSIG for all study site systems.

5.2 Element Number Variation Impact (Bluerock View)

It was determined in the design section 4.3.3 that the Bluerock view DAC would require alternating the number of elements-in-series in operation from 2 to 3 to accommodate the design range of production which aims to meet the average consumption demand as well as the maximum consumption demand in said DAC. **Table 5.2A** Summarizes the range of results of the simulations conducted at both 2 and 3-element operation at Bluerock View and the impact it displays on meeting the nitrate concentration in the permeate design limit.

Table 5-2A: Simulation results summary for the element number variation (2 & 3) at Bluerock View study DAC based on the design range of specifications.

	Study DAC	
	Bluerock View, 2E	Bluerock View, 3E
Feed flowrate (GPD)	2111.1 - 2666.7	2666.7 - 4666.7
Number of elements	2	3
Permeate flowrate (GPD)	1900.0 - 2400.0	2400.0 - 4200.0
Concentrate flowrate (GPD)	211.1 - 266.7	266.7 - 466.7
Permeate flux (gfd)	11.18 - 14.12	9.41 - 16.47
Recovery (%)	90	90
Recycle Ratio	2.05 - 1.62	1.62 - 0.93
Cross-flow velocity (m/s)	0.13 - 0.16	0.16 - 0.28
Average single pass recovery	15.97	13.5
Feed salt concentration (mg/L)	1446.27	1446.27
Feed nitrate concentration (mg/L as NO_3^-)	180	180
Permeate salt concentration (mg/L)	118.18 - 96.11	132.49 - 71.06
Permeate nitrate concentration (mg/L as NO_3^-)	27.02 - 21.98	30.23 - 16.03
Intrinsic salt rejection (%)	91.83 - 93.35	90.84 - 95.09
Intrinsic nitrate rejection (%)	85.00 - 87.78	83.20 - 91.10
Permeate pH	6.43 - 6.34	6.48 - 6.21
Feed pressure (PSIG)	227.4 - 239.9	201.71 - 216.9
Concentrate pressure (PSIG)	225.9 - 238.2	199.2 - 213.6

Given that the Bluerock View community water production capacity was set to 1966 GPD, this capacity was about twice the average annual daily demand (894 GPD) plus an 11% safety factor. The RO system can produce the above average consumption demand in approximately 11 hours operation. The resulting permeate nitrate concentration is slightly above the design permeate concentration limit of 25 mg/L as NO_3^-, at 26.20 mg/L as NO_3^- operating at 1966.8 GPD and 11.57 gfd. The quality of the permeate can be improved by operating the RO at higher permeate flux settings, which in its turn reduces the time of RO system operation in terms of meeting the design production capacity mentioned above.

Bluerock View DAC has a maximum daily demand (noticed during the months May-August) of ~2,000 GPD. As a result, it is expected that the two-element in series configuration would have to operate continuously throughout the day in order to meet the maximum daily demand as the RO system with its two-element configuration could only produce up to 2,400 GPD before reaching element recovery limit of 20% and consequently prompting increased scaling potential. Therefore, the production capacity of the RO system would be increased by implementing a third element in a separate pressure vessel that would only be utilized if the community potable water reserves were noticed to be diminishing at a deficit with regard to the community demand. The implementation of a third element increases the production capacity's upper limit to 4,200 GPD (2.1 times that maximum daily demand observed in 2018, **Table 4-1B**) which offers flexibility in terms of producing potable water throughout the year. **Fig. 5-2A** compares the projected ranges of permeate production (flow and flux) for both 2-element (2E) and 3-element (3E) in series operation at Bluerock View.

It is noticed from the RO System Design Simulation results data (**Appendix D**) for the 3-elements-in-series configuration in Bluerock View that operating said configuration in lower permeate flux settings (less than 11.76 gfd) would yield permeate nitrate concentrations larger than 25 mg/L as NO_3^-; as a result, the operation of the three element RO would have to fall within the specified flux range of 12-17 gfd to guarantee the production of potable water up to the design-specified water quality standards.

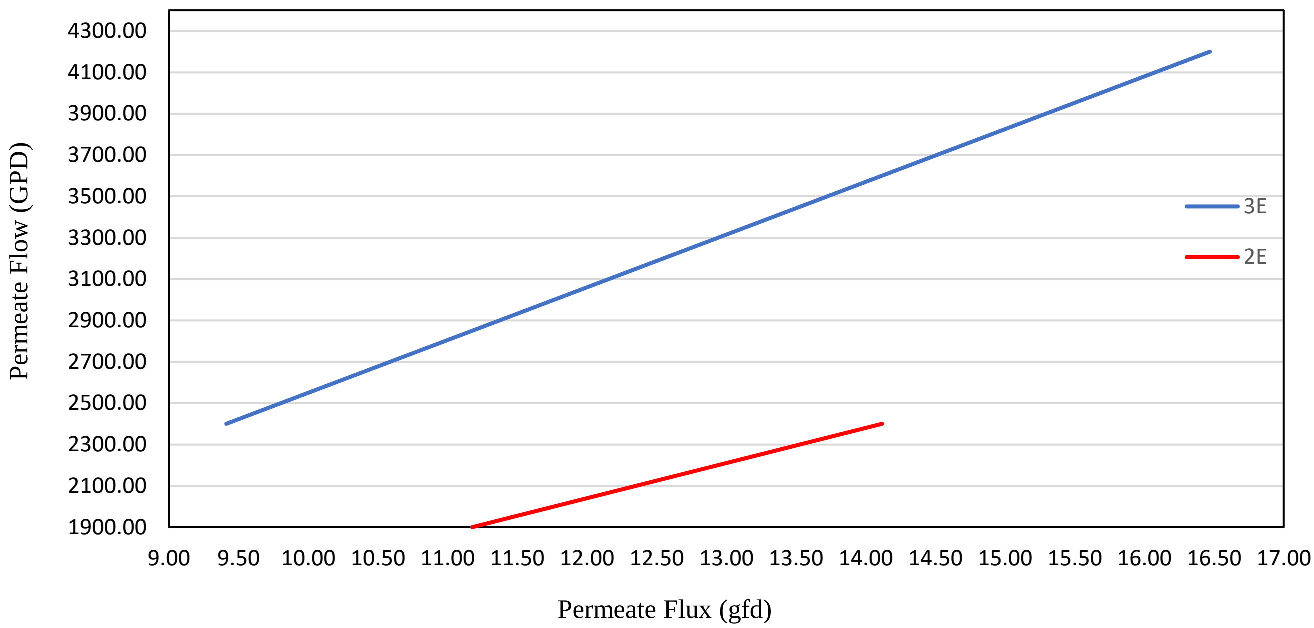

Figure 5-2A: RO water production capacity (GPD) as a function of permeate flux for the 2 & 3-element-in-series (2E & 3E respectively) configuration for the Bluerock View RO treatment system. The 2E configuration covers the Bluerock design production capacity of 1966 GPD (covering 2.2 times the yearly averaged demand) with an upper range limit of 2,400 GPD. The 3E configuration covers the extent of treatment if it is desired for the system to produce more than 2,400 GPD (Bluerock has a summer-time Maximum Daily Demand of ~2,000 GPD) up to an upper range limit of 4,200 GPD.

5.3 Element Breaking Point & Safe Point Limits

The element breaking point can be defined as the point of which the RO system begins producing permeate of nitrate concentration above the EPA MCL limit of 45 mg/L as NO_3^-. Estimating the element breaking point was conducted through conducting CSMPro5 simulations based on the design RO treatment specifications (**Tables 4-1A & B**) with the design production capacity for each site, while increasing the nitrate concentration (with adequate ion reconciliation with OLI studio) until reaching the EPA nitrate MCL of 45 mg/L as NO_3^- in the permeate side of the treatment system. **Table 5-3A** summarizes the results from conducting the RO system treatment breaking point simulations conducted for the three study sites (Bluerock, Santa Teresa, Pryor Farms) at their design production capacity and design specifications.

Table 5-3A: Simulation results of routine (design) operation extent of treatment before reaching the EPA nitrate MCL in the permeate (45 mg/L as NO_3^-).

	Study DAC (Number of elements in series)		
	Bluerock View (2E)	Santa Teresa Farms (3E)	Pryor Farms (4E)
Design permeate flowrate (GPD)	1966.8	3071.2	5601.2
Current source well nitrate concentration (mg/L as NO_3^-)	180	45	101.7
Maximum allowable feed nitrate concentration until reaching EPA MCL (mg/L as NO_3^-)	310	360	575
Resulting permeate nitrate concentration (mg/L as NO_3^-)	45.29	45.27	45.14

During the routine (design) RO system operation, **Table 5-3A** shows that Bluerock View system design is capable of treating feed nitrate concentrations of up to 310 mg/L as NO_3^- until reaching the maximum extent of treatment and producing a permeate with nitrate concentration of 45.29 mg/L as NO_3^-. Furthermore, **Table 5-3A** shows that for the two remaining DACs, Santa Teresa and Pryor Farms, the extent of treatment under routine (design) operation is capable of treating feed nitrate concentrations of up to 360 and 575 mg/L as NO_3^- for Santa Teresa and Pryor Farms (well "6") respectively before reaching a permeate nitrate concentration of 45.27 and 45.14 mg/L as NO_3^- respectively. **Figures 5-3A** to **B** illustrate the permeate nitrate concentration as a function of feed nitrate concentrate during routine operation (check **Table 4-1B** for specifications) for each study DAC until reaching the maximum allowable nitrate MCL (45 mg/L as NO_3^-).

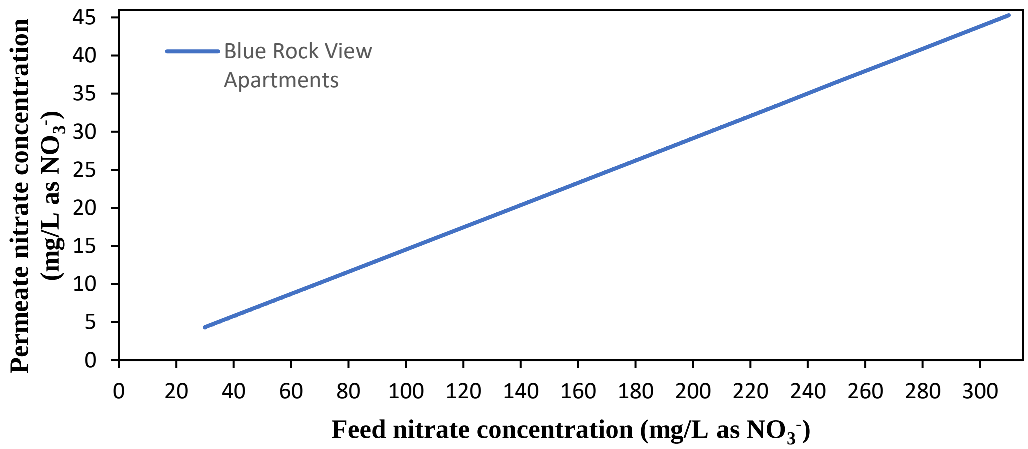

Figure 5-3A: Bluerock View Apartments DAC extent of treatment simulations trendline under routine operation (2E) at 1966.8 GPD production capacity.

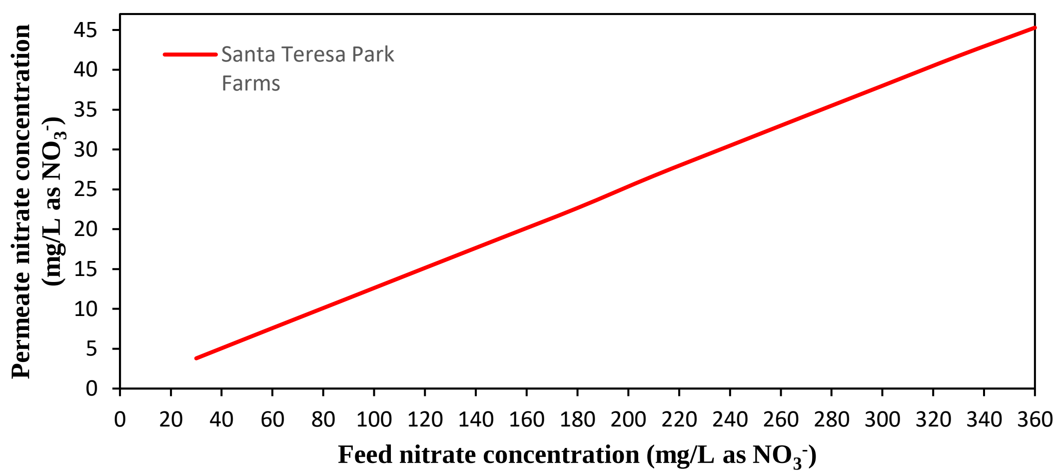

Figure 5-3B: Santa Teresa Park Farms DAC extent of treatment simulations trendline under routine operation (3E) at 3071.2 GPD production capacity.

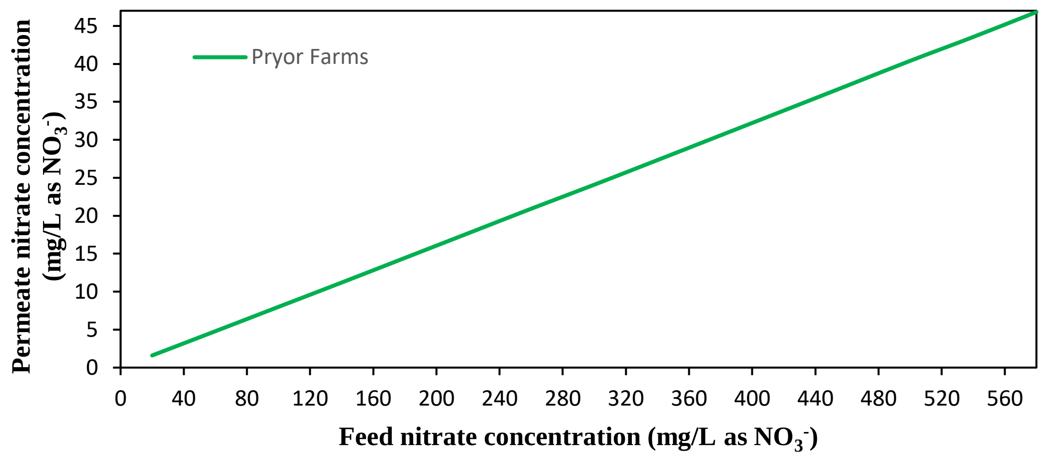

Figure 5-3C: Pryor Farms DAC well "6" extent of treatment simulations trendline under routine operation (4E) at 5601.2 GPD production capacity.

In addition to exploring maximum allowable nitrate level in the feed, each DAC was simulated under a pre-specified range of production capacities (**Table 4-3A**) while varying the feed nitrate concentration (with suitable ion neutralization using OLI Studio) until reaching the maximum design permeate nitrate concentration limit of 25 mg/L as NO_3^-. The above mentioned permeate nitrate concentration of 25 mg/L was simulated to explore the maximum allowable nitrate concentration in the feed source water at different production capacities before reaching the above mentioned "safe point". **Table 5-3B** summarizes the results from conducting the RO system treatment "safe point" simulations conducted for the three study sites (Bluerock, Santa Teresa, Pryor Farms) at a pre-specified range of production capacities (found in **Table 4-3A**).

Table 5-3B: "Safe Point" (Perm. Conc. of 25 mg/L as NO_3^-) at design range of production capacity simulation results summary.

	Study DAC (Number of elements)		
	Bluerock View (2E)	Santa Teresa Park (3E)	Pryor Farms Well "6" (4E)
Production capacity range (GPD)	1,900 - 2,400	2,700 - 4,100	5,350 - 5,800
Corresponding allowable feed nitrate concentration range (mg/L as NO_3^-)	167 - 205	171 - 279	304 - 334
Resulting permeate nitrate concentration (mg/L as NO_3^-)	25 ± 0.07	25 ± 0.05	25 ± 0.06

Bluerock View Apartments DAC RO system is found to be capable of producing a permeate with nitrate concentration of 25 mg/L as NO_3^- or less within a production range of 1,900 – 2,400 GPD (2-element operation), provided that the corresponding feed nitrate concentration range is 167 – 205 mg/L as NO_3^- respectively. Santa Teresa Park Farms DAC RO system is able to produce permeate with nitrate concentration of 25 mg/L as NO_3^- or less within a production range of 2,700 – 4,100 GPD (3-element operation), provided that the corresponding feed nitrate concentration range is 171 – 279 mg/L as NO_3^- respectively. Finally, Pryor Farms well "6" RO system is capable of producing RO permeate with nitrate concentration of 25 mg/L as NO_3^- or less within a production range of 5,350 – 5,800 GPD (4-element operation), provided that the corresponding feed nitrate concentration range is 304 – 334 mg/L as NO_3^- respectively.

5.4 Two-Pass Configuration Operation Results

The Two-Pass configuration **(Fig. 4-3C)** is within the list of optional installations at any site, and it is prompted only when a certain site is found to be producing a permeate with nitrate concentration exceeding the "Safe Point" limit of 25 mg/L as NO_3^- throughout the range of design production capacities (**Table 4-3A**). Pryor Farms well "L" single-pass simulation results, as summarized in **Table 5-1A**, meets the criteria mentioned above and as result; has been considered for potential two-pass operation. RO System Design for two-pass configuration based on the design specifications listed in **Table 4-3D** demonstrated capability for producing permeate of nitrate level below the maximum set level (Safe Point) of 25 mg/L as NO_3^-. RO System Design Simulation results for each pass using the two-pass configuration at Pryor Farms well "L" (389.7 mg/L nitrate feed concentration) are summarized in **Table 5-4A**. Two-pass system production results are summarized in **Table 5-4B**.

Table 5-4A: RO System Simulation results for each pass for a two-pass RO configuration for water treatment at Pryor Farms well "L" (389.7 mg/L nitrate feed concentration).

1st Pass		**2nd Pass**	
Feed flowrate (GPD)*	8400 - 9730	**1st Pass Permeate to 2nd Pass Permeate Blending (GPD)**	2520 - 2920
Number of elements	6	**Feed flowrate (GPD)**	5040 - 5840
Permeate flowrate (GPD)	7560 - 8760	**Number of elements**	4
Concentrate flowrate (GPD)	840 - 973	**Permeate flowrate (GPD)**	2520 - 2920
Permeate flux (gfd)	14.82 - 17.18	**Concentrate flowrate (GPD)*****	2520 - 2920
Recovery (%)	90	**Permeate flux (gfd)**	7.41 - 8.95
Average single pass recovery (%)	10.17	**Recovery (%)**	50
Recycle Ratio	0.51 - 0.45	**Average single pass recovery (%)**	12.52
Cross-flow velocity (m/s)	0.46 - 0.53	**Cross-flow velocity (m/s)**	0.31 - 0.35
Source feed salt concentration (mg/L)**	1618.9	**Feed salt concentration (mg/L)**	51.72 - 42.72
Source feed nitrate concentration (mg/L as NO_3^-)**	389.7	**Feed nitrate concentration (mg/L as NO_3^-)**	21.93 - 18.13
Permeate salt concentration (mg/L)	51.72 - 42.72	**Permeate salt concentration (mg/L)**	1.38 - 1.01
Permeate nitrate concentration (mg/L as NO_3^-)	21.93 - 18.13	**Permeate nitrate concentration (mg/L as NO_3^-)**	0.76 - 0.55
Intrinsic salt rejection (%)	96.80 - 97.36	**Intrinsic salt rejection (%)**	97.64 - 97.33
Intrinsic nitrate rejection (%)	94.37 - 95.34	**Intrinsic nitrate rejection (%)**	96.96 - 96.53
Permeate pH	6.03 - 5.95	**Permeate pH**	4.49 - 4.35
Feed pressure (PSIG)	163.88 - 174.90	**Feed pressure (PSIG)**	47.16 - 54.9
Concentrate pressure (PSIG)	153.72 - 163.30	**Concentrate pressure (PSIG)**	45.46 - 52.7

* RO 1st pass feed flowrate = source water raw feed flowrate + 2nd pass concentrate flowrate. Feed flowrate values are reported before 1st pass recycle mix point.
** Source well water quality values at Pryor Farms well "L".
*** 2nd pass concentrate is redirected to join 1st pass feed prior to 1st pass recycle mix point.

Table 5-4B: Two-pass RO module configuration system simulation results for Pryor Farms well "L" (389.7 mg/L nitrate feed concentration).

Overall Two-Pass System Output	
Range of permeate production (GPD)	5040 - 5840
Overall recovery (%)	90
Total number of elements	10
Post blending permeate salt concentration (mg/L)*	26.55 - 21.85
Post blending permeate nitrate concentration (mg/L as NO_3^-)*	11.35 - 9.34
Range of RO system residual output (GPD)**	840 - 973

* Blending of 1st pass and 2nd pass permeate streams.
** Pryor Farms DAC septic tank volume = 5,000 gallons.

Process simulations for two-pass configuration for water treatment at Pryor Farms indicate that it is possible to treat high nitrate levels (~400 mg/L as NO_3^-) through utilization of a 1st pass operating at 90%, and a 2nd pass at 50% recovery with complete concentrate recycle back to the 1st pass. The final RO potable water product (post permeate blending) nitrate concentration ranges between 11.35 – 9.34 depending on the projected range of production. The above nitrate concentration is well below the design "Safe Point" limit of 25 mg/L as NO_3^-. The RO system residual output range of the two-pass configuration is slightly above the range resulting from single pass operation of 594.4 - 644.4 GPD (Table 5-1A), at 840 – 973 GPD. It is feasible to address the increase in residual output by following routine design operation as it only consists of ~ 16.8 – 19.5% volume of the current Pryor Farms septic tank, and about 9.3 – 10.8% volume of the combined residual storage tank (T-4, **Fig. 3-1**) and septic tank volumes (4,000 and 5,000 GPD respectively). **Fig. 5-4A** illustrates the simulated nitrate permeate concentration as a function of operable permeate flowrate for the Pryor Farms well "L" study case.

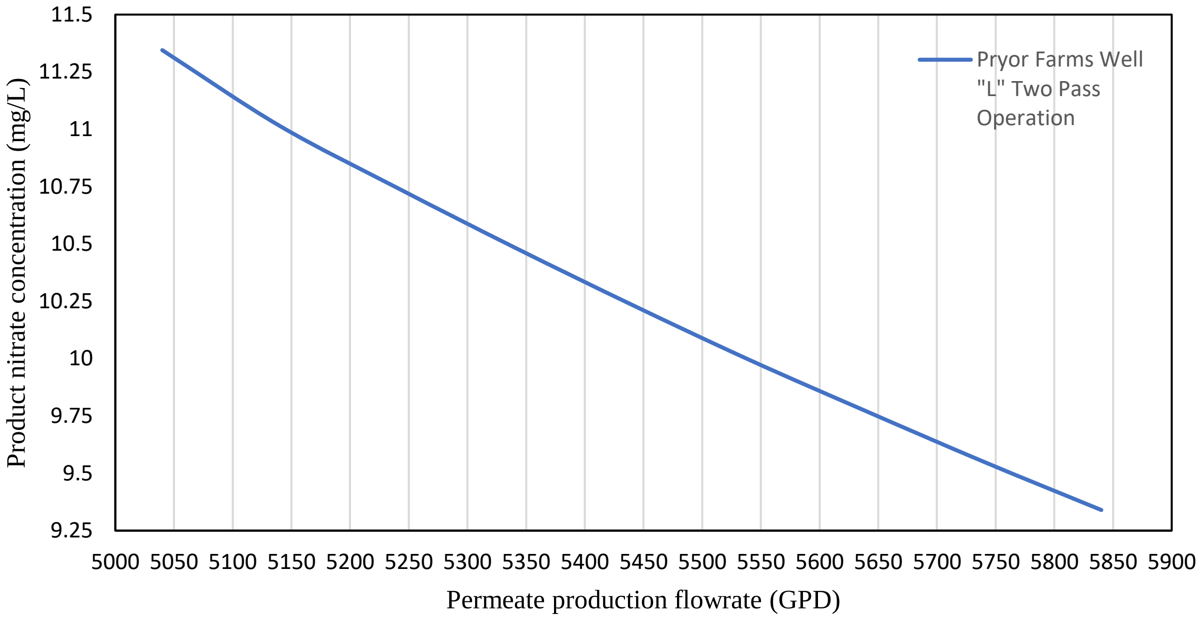

Figure 5-4A: simulated nitrate permeate concentration as a function of operable permeate flowrate for the Pryor Farms well "L" study case.

An alternative TO system design for water treatment at Pryor well "L" (~400 mg/L as NO_3^-) for producing a permeate with nitrate concentration below the "Safe Point" limit of 25 mg/L as NO_3^- is possible through 6 elements operation for 1st Pass configuration shown in **Table 5-4A**. The resulting configuration would require less hours of operation for the RO system to produce the design volume of potable water for Pryor Farms (5600 GPD), as it produces 7,560 – 8,760 GPD. However, the 6-element operation is producing permeate of nitrate levels ranging 21.93 – 18.13 mg/L as NO_3^- which is close to the "Safe Point" limit of 25 mg/L as NO_3^-. Given that the well under consideration in this case (well "L") has been experiencing increased concentrations of nitrate throughout a short period of time (389.7 mg/L in 2017 from 97 mg/L in 2015, **Appendix A**); the above mentioned 6-element single pass treatment operation is under the risk of being insufficient in meeting the "Safe Point" limit if the nitrate increasing trend continues in the mentioned site well, and would yet again need an increase in element number to produce better quality permeate. Upon increasing the number of elements; the operational flux would have to be increased in order to maintain the permeate quality, which in turn yields higher system residual volume output. As a result, resulting to a two-pass configuration is thought to yield more reliable product quality over large range of nitrate feed concentrations, as well as having a lower system residual volume output than the single-stage with increased element-count operation alternative.

Fig. 5-4B illustrates the extent of treatment for a two-pass configuration at Pryor Farms well "L" before reaching the EPA MCL of 45 mg/L as NO_3^-.

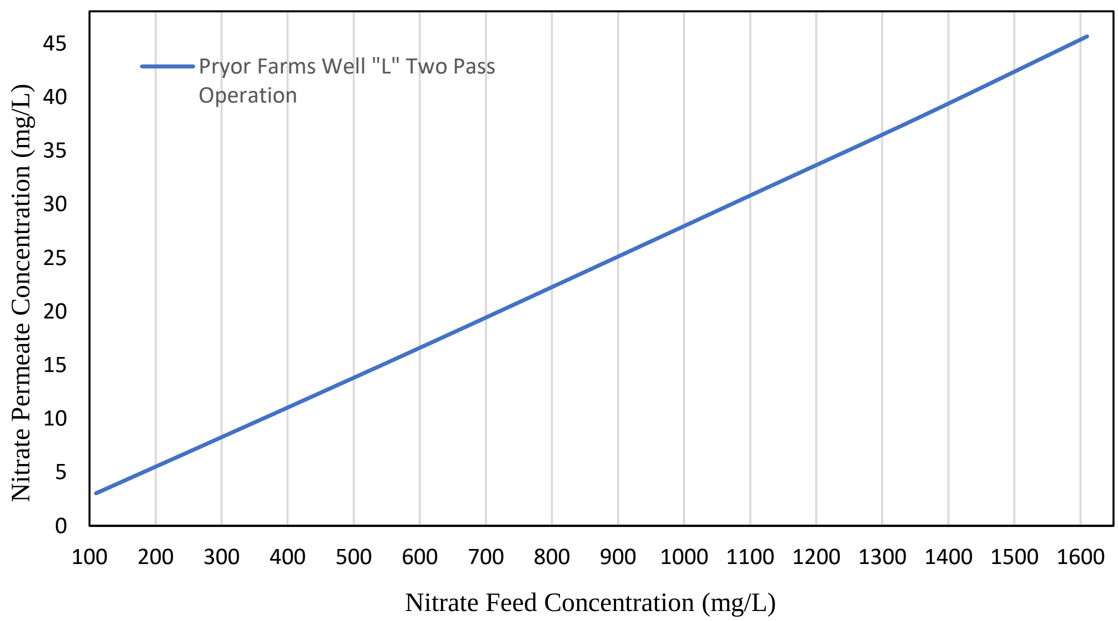

Figure 5-4B: Pryor Farms DAC well "L" extent of treatment simulations trendline under two-pass configuration operation (10E) at 5,600 GPD production capacity.

The two-pass configuration at Pryor Farms well "L is able to treat feed nitrate concentrations at 90% recovery of up to 1,600 mg/L as NO_3^- before reaching the EPA MCL of 45 mg/L as NO_3^-. Pryor Farms community management has decided to relocate the designated well of treatment to the nearby on-site well “6” (101.7 mg/L as NO_3^- feed concentration) that can be effectively treated with a single-stage RO configuration.

5.5 Correlation of RO Nitrate Passage with to Salt Passage

In order to monitor for RO performance degradation, one can monitor the permeate salinity as a surrogate for the passage of nitrate. However, such an approach requires one to determine if there is a correlation between salt passage and nitrate passage. Accordingly, process simulations were carried out. A site-specific simulated nitrate passage-salt passage correlation was generated for all sites to include multiple operational recoveries (50, 70, and 90%), covering operational flux range 10-15 gfd, and three different site-specific nitrate concentrations. **Figures 5-5A** to **C** illustrate the simulated site-specific nitrate passage-salt passage correlation plots at 90% recoveries for Bluerock View Apartments, Santa Teresa Park, and Pryor Farms DACs respectively. Additional figures covering 50% and 70% recovery operations can be found in **Appendix D**.

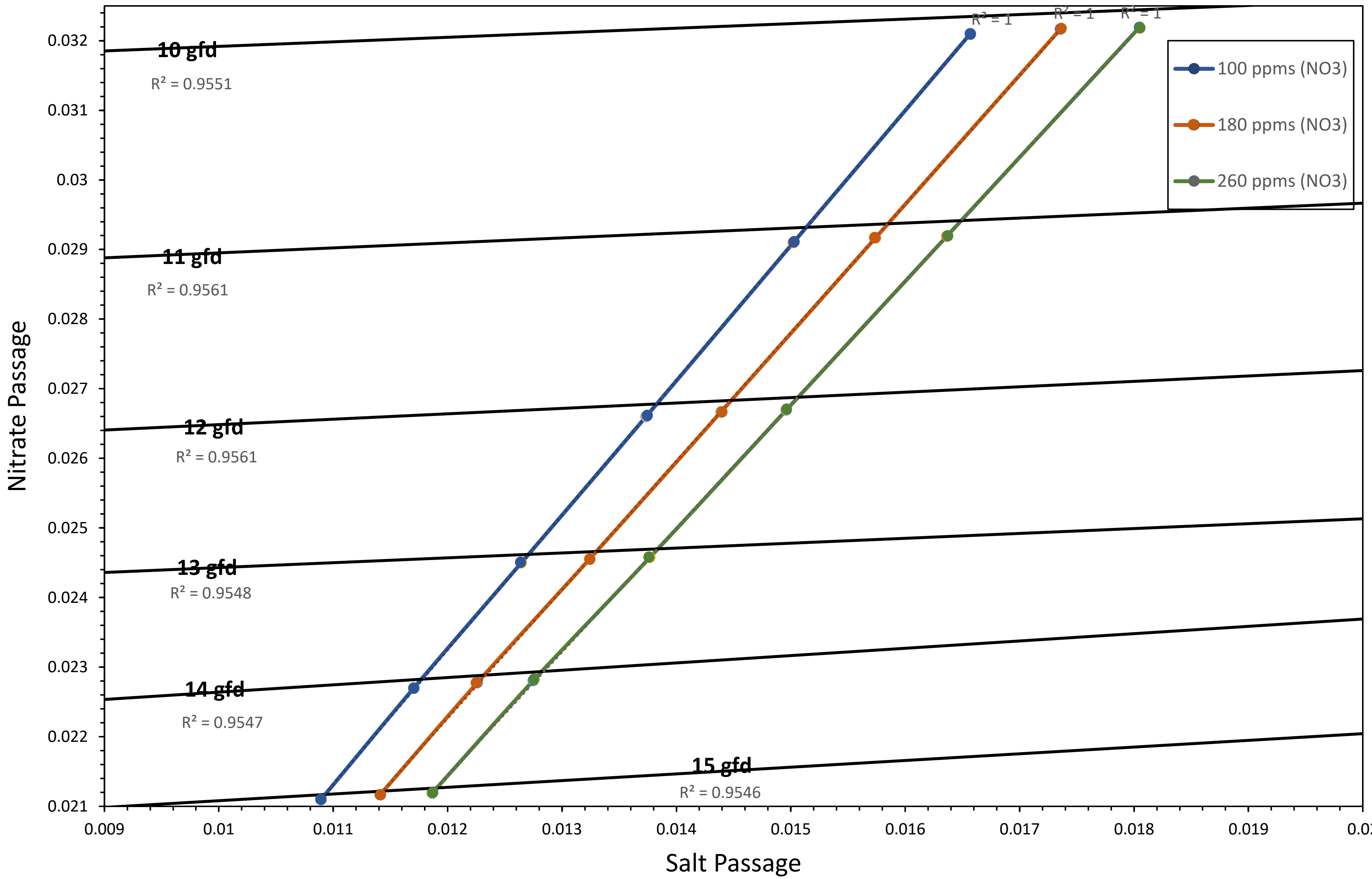

Figure 5-5A: Salt passage-nitrate passage correlation of different feed nitrate concentrations (100, 180, and 260 mg/L as NO_3^-) at 90% recovery. Isoflux lines are indicated by the color black, followed by their coefficient of determination value. Nitrate levels in the well water for water treatment at Bluerock apartments were 180 mg/L as NO_3^-.

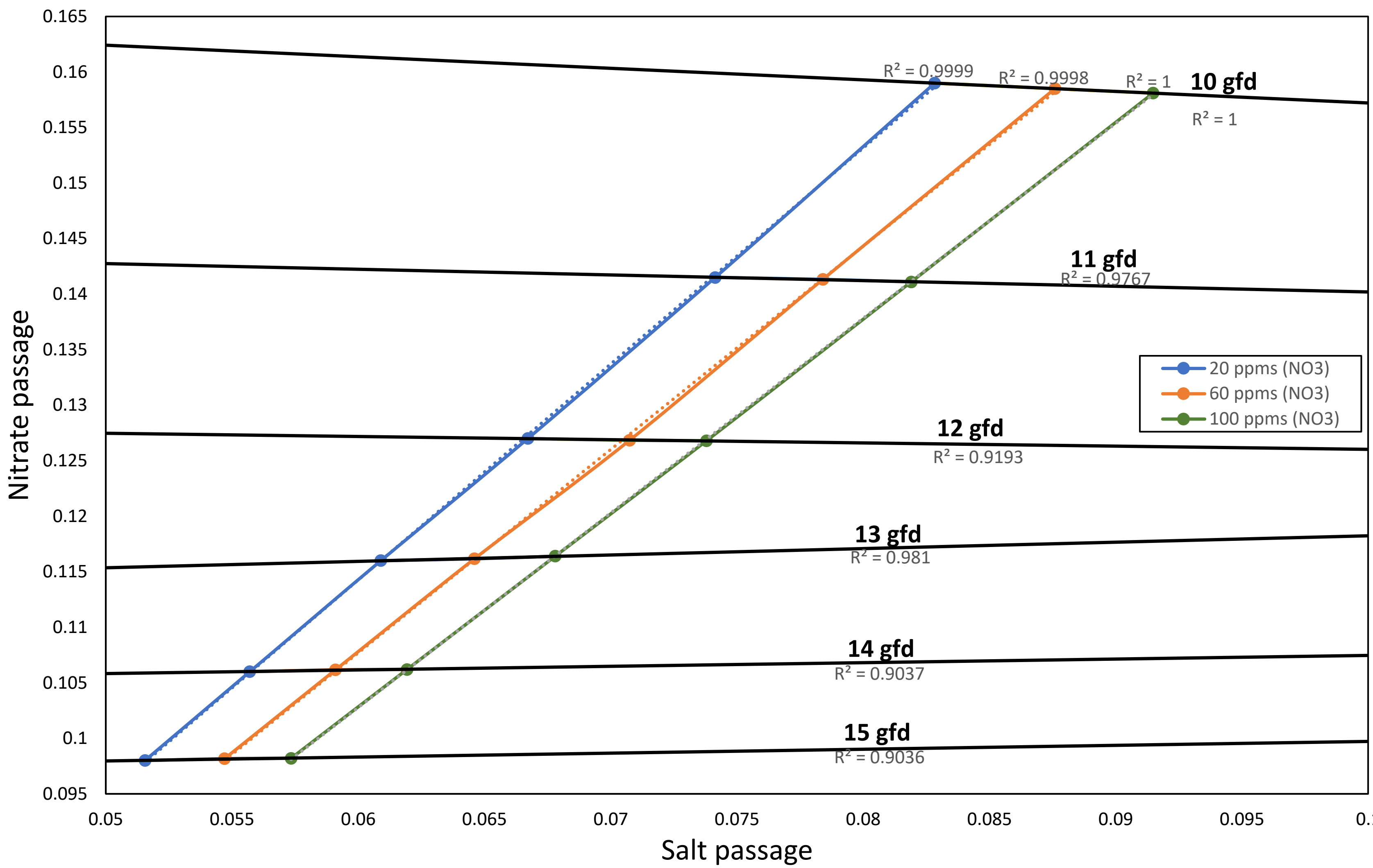

Figure 5-5B: Salt passage-nitrate passage correlation of different feed nitrate concentrations (20, 60, and 100 mg/L as NO_3^-) at 90% recovery. Isoflux lines are indicated by the color black, followed by their coefficient of determination value. Nitrate levels in the well water for water treatment at Santa Teresa Park were 45 mg/L as NO_3^-.

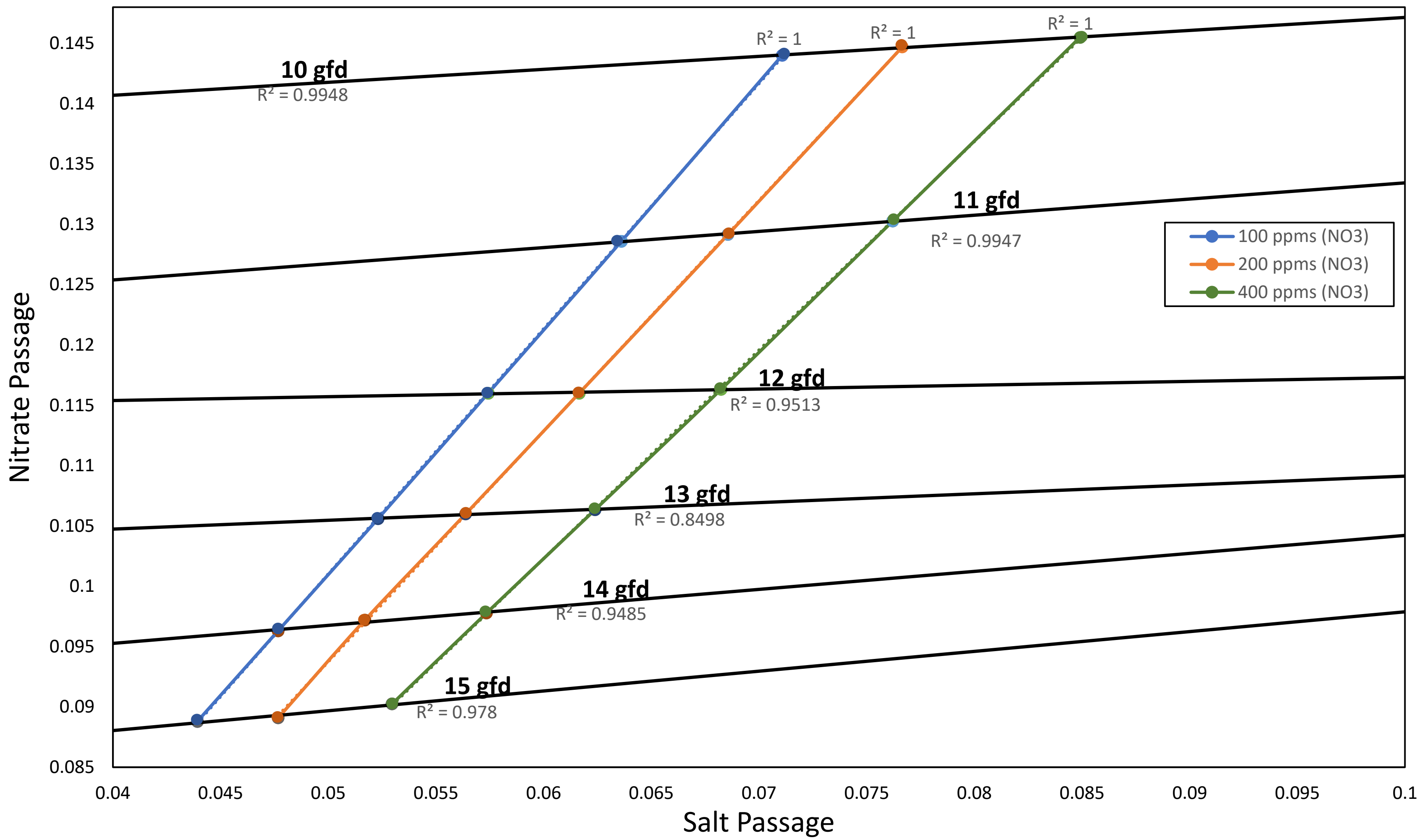

Figure 5-5C: Salt passage-nitrate passage correlation of different feed nitrate concentrations (100, 200, and 400 mg/L as NO_3^-) at 90% recovery. Isoflux lines are indicated by the color black, followed by their coefficient of determination value. Nitrate levels in the well water for water treatment at Pryor Farms were 101.7 mg/L as NO_3^-.

The previous figures allow for the calculation of nitrate passage based on the corresponding reported value of salt passage in the DACs RO system permeate. Therefore, Salt (Total Dissolved Solids or TDS) concentration (mg/L) in the permeate must be translated from onsite conductivity values (mS/cm) collected via the permeate site conductivity transmitter (CT 02 in Fig. 3-1A). A TDS (mg/L) as a function of conductivity (mS/cm) was established using OLI Studio simulations of site-specific water profiles at a wide range of salt concentrations (~1000 iterations). The OLI TDS-Conductivity correlation shown in **Figure 5-5D** is generated from running a water composition concentration survey via OLI studio. The survey concentrates the feed water within user-indicated iterations (1000 points were used in this approach) with each iteration generating both TDS and conductivity result point at a value-increasing notion for both due to concentration increase of sample. Upon collecting all OLI survey results; a DAC-specific TDS-Conductivity correlation is generated based on the survey results. **Figure 5-5D** illustrates the TDS concentration (mg/L) of the Bluerock View DACs as a function of conductivity (mS/cm). Additional site-specific TDS-conductivity correlations can be found in **Appendix D**.

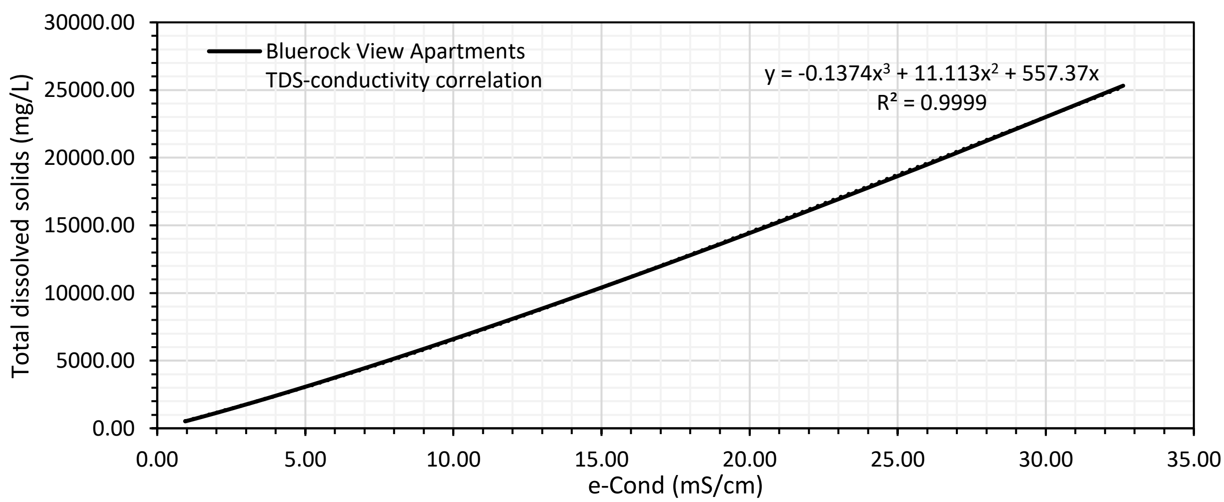

Figure 5-5D: TDS concentration (mg/L) of the Bluerock View DACs as a function of conductivity (mS/cm) using OLI studio.

Chapter 6

6. Summary and Conclusion

A process and system design were developed and analyzed for the integration of continuous and high recovery RO treatment system into Disadvantaged Remote Communities (DACs) for the intent of nitrate removal and salinity reduction. The feasibility of the DAC RO system was assessed via analysis of the system's capability in meeting community potable water needs, as well as meeting community septic system limitations through partial concentrate recycle to achieve high recovery operation (90% recovery).

1- RO process design specifications were derived on the basis of optimizing continuous high recovery operation in producing design permeate capacity ranging from 1966 – 5600 GPD via RO module treatment of brackish water with feed nitrate concentrations ranging at 45 – 389.7 mg/L as NO_3^-, and salinity concentrations ranging at 564 – 1927.1 mg/L as total dissolved solids (TDS).

2- RO system design specifications were derived on the basis of reducing the RO system's septic system footprint; producing system concentrate consisting of 4.86 – 12.45% of the total septic tank capacity per day through partial concentrate recycle to achieve high recovery operation (90% recovery).

3- System pretreatment design was developed to remove suspended particles in the RO feed ranging from 300 - 5µm in diameter through multiple filter mediums. Antiscalant reservoir and dosing pump are added in the event that the fresh water flush method is unable to consistently mitigate scale accumulation on the RO membrane. Optional connections to the pretreatment section were considered for the addition of future specialized filtration options (i.e. green sand filters).

4- RO system post-treatment design was developed to stabilize RO permeate pH (6 – 6.5) through a remineralization bed to improve taste, and reduce susceptibility for pipe corrosion. Optional disinfection reservoir and metering pump were added to the post-treatment section design to ensure a constant dose of 0.2 mg/L of chlorine disinfectant is present if needed.

5- RO treatment operation for the above range of permeate production at high recovery (90%) was found feasible through the utilization of 2-4 elements in series (RE-4040BE) while operating below the maximum recommended average element recovery value of 20% per element. The above-mentioned design treatment operation is operated under an average single-pass recovery range of 13.05 – 15.15%.

6- RO System Design simulations (CSMPro5 and OLI Studio) indicate that it is feasible to produce potable water at the above-mentioned production ranges with permeate nitrate concentrations less than the design-specified "Safe Point" limit of 25 mg/L as NO_3^- at all study DACs of concern.

7- Two-pass operation was deemed feasible in the event that high spikes of nitrate concentration were noticed in the community source well that would lead to RO operation permeate nitrate concentration higher than 25 mg/L as NO_3^- when operated at the recommended design flux range of 12-17 gfd.

8- A site-specific correlation between permeate conductivity and permeate nitrate concentration was found for the study DACs via CSMPro5 and OLI RO System Design software simulations that reduces the frequency of use of cost-heavy permeate nitrate transmitters/sensors.

In order to optimize the operation of the high recovery RO treatment system for nitrate removal in disadvantaged communities; it is critical to establish a remote (and on-site) supervisory system that would receive and record the data transmitted by the different on-stream transmitters to maintain safe and continuous operation. In addition, system design simulation results presented in this study would have to be verified through site-specific field operation of the system (i.e. during system commissioning period). It is important to monitor RO membrane scaling during routine operation to determine the effect of fresh water flush operation mode on scale detergence, and whether antiscalants are required.

It is imperative to construct a permeate conductivity (mS/cm) and permeate total dissolved solids (mg/L as ion) correlation via OLI Studio upon start-up of field operation at any site of operation, and to verify the correlation with lab-measured water quality results that show both values (conductivity and TDS) in order to establish a TDS reference for the permeate from conductivity readings. Upon establishing and verifying the above conductivity-TDS correlation, a similar approach should be followed with nitrate measurements at the permeate to establish a nitrate correlation that could be paired with TDS concentration at the permeate as discussed in **§4.3.5** & **§5.5**.

Appendices

Appendix A: Water Quality Results

Table A-1: Bluerock View Apartments WQR (9/22/2015 – 9/15/2018).

Analyte (Unit)	Result	MCL	Date measured
Alkalinity (mg/L as CaCO3)	348		9/22/2015
Aluminum (µg/L)	ND	1000	
Arsenic (µg/L)	2	10	
Asbestos (mF/L)	ND	7	
Barium (µg/L)	45	1000	
Beryllium (µg/L)	ND	4	
Bicarbonate (mg/L as HCO3-)	425		
Boron (mg/L)	0.33		
Bromide (mg/L)	0.7		
Cadmium (µg/L)	ND	5	
Calcium (mg/L)	193		
Carbonate (mg/L as CaCo3)	ND		
Chloride (mg/L)	217	250	
Chromium VI (µg/L)	1.7		
Chromium, Total (µg/L)	12	50	
Coliform, E. Coli (MPN/100mL)	ND	1	
Coliform, E. Coli (MPN/100mL)	ND	1	9/15/2018
Coliform, Total (MPN/100mL)	ND	1	9/22/2015
Coliform, Total (MPN/100mL)	ND	1	9/15/2018
Color (Color units)	ND	15	9/22/2015
Copper (µg/L)	ND	1300	
Copper (µg/L)	75.1	1300	9/15/2018
Cyanide (µg/L)	ND	200	9/22/2015
Fluoride (mg/L)	0.2	2	
Hardness (mg/L as CaCO3)	787		
Hydroxide (mg/L)	ND		
Iron (µg/L)	ND	300	
Iron (µg/L)	26	300	9/15/2018
Lead (µg/L)	ND	5	9/22/2015
Lead (µg/L)	ND	5	9/15/2018

Magnesium (mg/L)	74		9/22/2015
Manganese (µg/L)	ND	50	
Mercury (µg/L)	ND	2	
Nickel (µg/L)	ND	100	
Nitrate (mg/L as NO3)	287	45	
Nitrate (mg/L as NO3)	180	45	8/17/2017
Nitrate (mg/L as NO3) (TAP)*	40.95	45	9/15/2018
Nitrite (mg/L as NO2-N)	0.2	1	9/22/2015
Odor Threshold at 60 C	3	3	
Perchlorate (µg/L)	2.1		
pH	7.3		
Potassium (mg/L)	6.2		
Selenium (µg/L)	23	50	
Sodium (mg/L)	174		
E-cond (mS/cm)	2.29	0.9	
Sulfate (mg/L)	326	250	
TOC (mg/L)	1.7		
Total Diss. Solids (mg/L)	1500	500	
Total Diss. Solids (mg/L)	1126	500	9/15/2018
Turbidity (NTU)	0.15	5	9/22/2015
Turbidity (NTU)	ND	5	9/15/2018
Zinc (µg/L)	ND	50000	9/22/2015

* TAP = sample collected from community kitchen tap.

Table A-2: Santa Teresa Farms WQR (9/22/2015 – 9/15/2018).

Analyte (Unit)	Result	MCL	Date measured
Alkalinity (mg/L as CaCO3)	112		9/22/2015
Aluminum (µg/L)	501	1000	
Arsenic (µg/L)	2	10	
Asbestos (mF/L)	ND	7	
Barium (µg/L)	162	1000	
Beryllium (µg/L)	ND	4	
Bicarbonate (mg/L as HCO3-)	137		
Boron (mg/L)	0.09		
Bromide (mg/L)	0.4		
Cadmium (µg/L)	ND	5	
Calcium (mg/L)	62		
Carbonate (mg/L as CaCo3)	ND		
Chloride (mg/L)	154	250	

Chromium VI (µg/L)	2.2		
Chromium, Total (µg/L)	5	50	
Coliform, E. Coli (MPN/100mL)	ND	1	
Coliform, E. Coli (MPN/100mL)	ND	1	9/15/2018
Coliform, Total (MPN/100mL)	ND	1	9/22/2015
Coliform, Total (MPN/100mL)	ND	1	9/15/2018
Color (Color units)	8	15	9/22/2015
Copper (µg/L)	ND	1300	
Copper (µg/L)	21.8	1300	9/15/2018
Cyanide (µg/L)	ND	200	
Fluoride (mg/L)	ND	2	
Hardness (mg/L as CaCO3)	245		9/22/2015
Hydroxide (mg/L)	ND		
Iron (µg/L)	777	300	
Iron (µg/L)	13	300	9/15/2018
Lead (µg/L)	ND	5	9/22/2015
Lead (µg/L)	ND	5	9/15/2018
Magnesium (mg/L)	22		
Manganese (µg/L)	ND	50	
Mercury (µg/L)	ND	2	9/22/2015
Nickel (µg/L)	ND	100	
Nitrate (mg/L as NO3)	46	45	
Nitrate (mg/L as NO3)	50	45	8/17/2017
Nitrate (mg/L as NO3) (TAP)*	45	45	9/15/2018
Nitrite (mg/L as NO2-N)	0.2	1	
Odor Threshold at 60 C	2	3	
Perchlorate (µg/L)	ND		
pH	7.4		
Potassium (mg/L)	4.4		
Selenium (µg/L)	2	50	9/22/2015
Sodium (mg/L)	78		
E-cond (mS/cm)	0.93	0.9	
Sulfate (mg/L)	67	250	
TOC (mg/L)	0.5		
Total Diss. Solids (mg/L)	554	500	
Total Diss. Solids (mg/L)	556	500	9/15/2018
Turbidity (NTU)	3.2	5	9/22/2015
Turbidity (NTU)	0.12	5	9/15/2018
Zinc (µg/L)	ND	50000	9/22/2015

* TAP = sample collected from community kitchen tap.

Table A-3A: Pryor Farms Well "L" (decommissioned from operation) WQR (9/22/2015 – 9/15/2018).

Analyte (Unit)	Result	MCL	Date measured
Alkalinity (mg/L as CaCO3)	244		9/22/2015
Alkalinity (mg/L as CaCO3)	304		10/9/2017
Aluminum (µg/L)	ND	1000	9/22/2015
Arsenic (µg/L)	1	10	
Asbestos (mF/L)	ND	7	
Barium (µg/L)	44	1000	
Beryllium (µg/L)	ND	4	
Bicarbonate (mg/L as HCO3-)	298		
Boron (mg/L)	0.25		
Bromide (mg/L)	0.4		
Cadmium (µg/L)	ND	5	
Calcium (mg/L)	143		
Calcium (mg/L)	245		10/9/2017
Carbonate (mg/L as CaCo3)	ND		9/22/2015
Chloride (mg/L)	134	250	
Chloride (mg/L)	204	250	10/9/2017
Chromium VI (µg/L)	2.6		9/22/2015
Chromium, Total (µg/L)	11	50	
Coliform, E. Coli (MPN/100mL)	ND	1	
Coliform, E. Coli (MPN/100mL)	ND	1	9/15/2018
Coliform, Total (MPN/100mL)	26	1	9/22/2015
Coliform, Total (MPN/100mL)	Present	1	9/15/2018
Color (Color units)	ND	15	9/22/2015
Copper (µg/L)	ND	1300	
Copper (µg/L)	624	1300	9/15/2018
Cyanide (µg/L)	ND	200	9/22/2015
Fluoride (mg/L)	0.3	2	
Hardness (mg/L as CaCO3)	617		
Hydroxide (mg/L)	ND		
Iron (µg/L)	35	300	
Iron (µg/L)	31	300	9/15/2018
Lead (µg/L)	1.11	5	9/22/2015
Lead (µg/L)	ND	5	9/15/2018
Magnesium (mg/L)	63		9/22/2015
Magnesium (mg/L)	123		10/9/2017
Manganese (µg/L)	ND	50	9/22/2015
Mercury (µg/L)	ND	2	
Nickel (µg/L)	58	100	

Nitrate (mg/L as NO3)	97	45	
Nitrate (mg/L as NO3)	389.7	45	10/9/2017
Nitrate (mg/L as NO3) (TAP)*	366.75	45	9/15/2018
Nitrite (mg/L as NO2-N)	0.3	1	9/22/2015
Odor Threshold at 60 C	2	3	
Perchlorate (µg/L)	ND		
pH	7.6		
Potassium (mg/L)	3.7		
Potassium (mg/L)	5.1		10/9/2017
Selenium (µg/L)	6	50	9/22/2015
Sodium (mg/L)	114		
Sodium (mg/L)	193		10/9/2017
E-cond (mS/cm)	1.63	0.9	9/22/2015
Sulfate (mg/L)	357	250	
Sulfate (mg/L)	589	250	10/9/2017
TOC (mg/L)	1.1		9/22/2015
Total Diss. Solids (mg/L)	1091	500	
Total Diss. Solids (mg/L)	1927.1	500	10/9/2017
Turbidity (NTU)	0.15	5	9/22/2015
Turbidity (NTU)	0.06	5	9/15/2018
Zinc (µg/L)	94	50000	9/22/2015

* TAP = sample collected from community kitchen tap.

Table A-3B: Pryor Farms Well “6” WQR (10/8/2018).

Analyte (Unit)	Result	MCL	Date measured
Alkalinity (mg/L as CaCO3)	257		10/8/2018
Aluminum (µg/L)	ND	1000	
Arsenic (µg/L)	2	10	
Asbestos (mF/L)	ND	7	
Barium (µg/L)	22.3	1000	
Beryllium (µg/L)	ND	4	
Bicarbonate (mg/L as HCO3-)	314		
Boron (mg/L)	ND		
Bromide (mg/L)	0.4		
Cadmium (µg/L)	ND	5	
Calcium (mg/L)	137		
Carbonate (mg/L as CaCo3)	ND		
Chloride (mg/L)	125	250	
Chromium VI (µg/L)	ND		
Chromium, Total (µg/L)	8.3	50	
Coliform, E. Coli (MPN/100mL)	ND	1	

Coliform, Total (MPN/100mL)	ND	1	
Color (Color units)	ND	15	
Copper (µg/L)	ND	1300	
Cyanide (µg/L)	ND	200	
Fluoride (mg/L)	0.2	2	
Hardness (mg/L as CaCO3)	625		
Hydroxide (mg/L)	ND		
Iron (µg/L)	ND	300	
Lead (µg/L)	ND	5	
Magnesium (mg/L)	69		
Mercury (µg/L)	ND	2	
Nickel (µg/L)	ND	100	
Nitrate (mg/L as NO3)	101.7	45	
Nitrite (mg/L as NO2-N)	ND	1	
Odor Threshold at 60 C	ND	3	
Perchlorate (µg/L)	ND		
pH	7.5		
Potassium (mg/L)	4		
Selenium (µg/L)	7	50	
Sodium (mg/L)	128		
E-cond (mS/cm)	1.61	0.9	
Sulfate (mg/L)	353	250	
TOC (mg/L)	ND		
Total Diss. Solids (mg/L)	1160	500	
Turbidity (NTU)	ND	5	
Zinc (µg/L)	ND	50000	

Appendix B: Modes of Operation

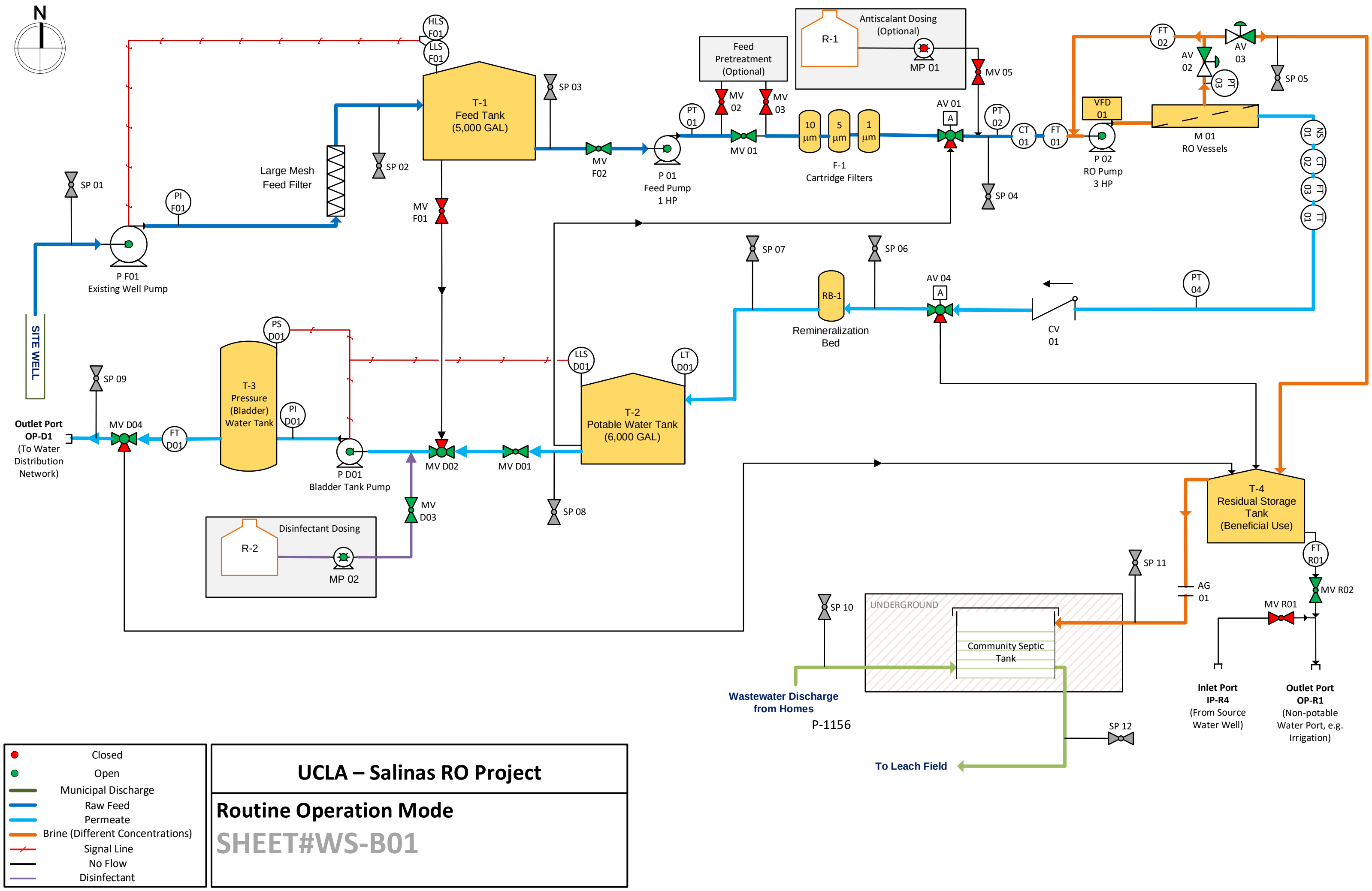

Figure B-1: *Process Flow Diagram (PFD) for the Routine Operation mode of operation in the RO Systems for Nitrate Removal in Disadvantaged Remote Communities in the Salinas Valley project. Stream color-code is presented at the bottom left corner.*

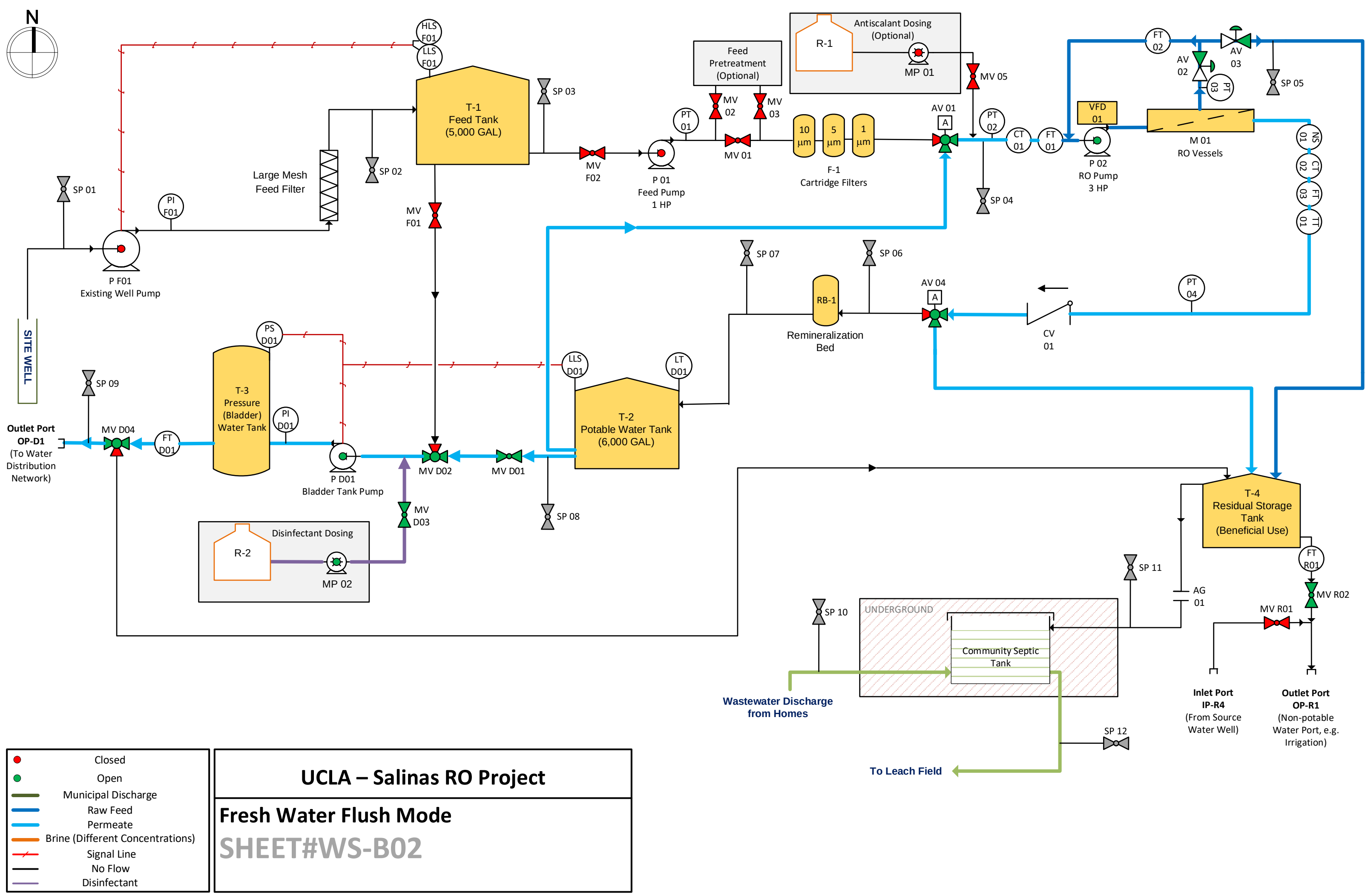

Figure B-2: *Process Flow Diagram (PFD) for the Fresh Water Flush mode of operation in the RO Systems for Nitrate Removal in Disadvantaged Remote Communities in the Salinas Valley project. Stream color-code is presented at the bottom left corner.*

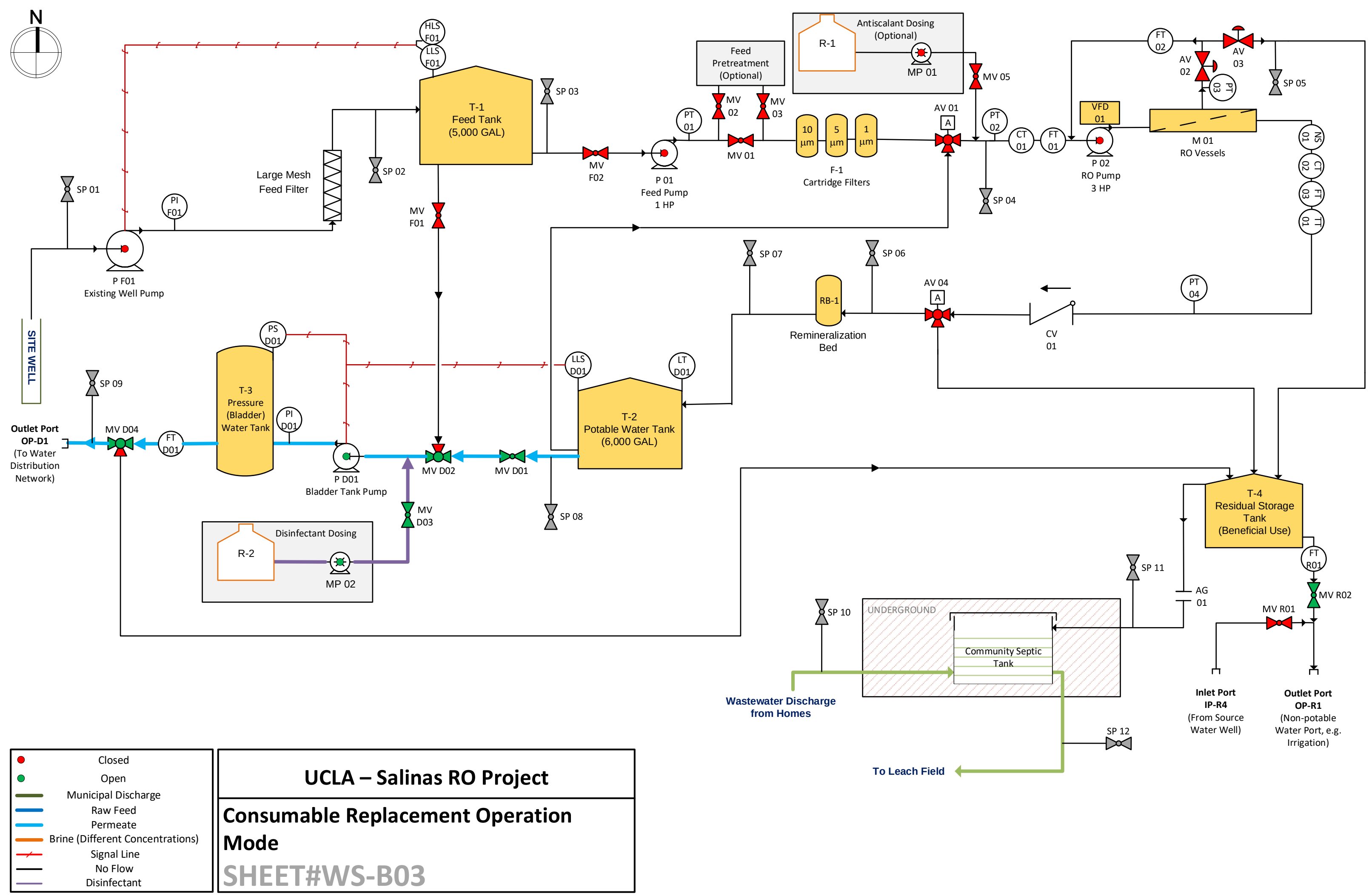

Figure B-3: *Process Flow Diagram (PFD) for the Consumable Replacement mode of operation in the RO Systems for Nitrate Removal in Disadvantaged Remote Communities in the Salinas Valley project. Stream color-code is presented at the bottom left corner.*

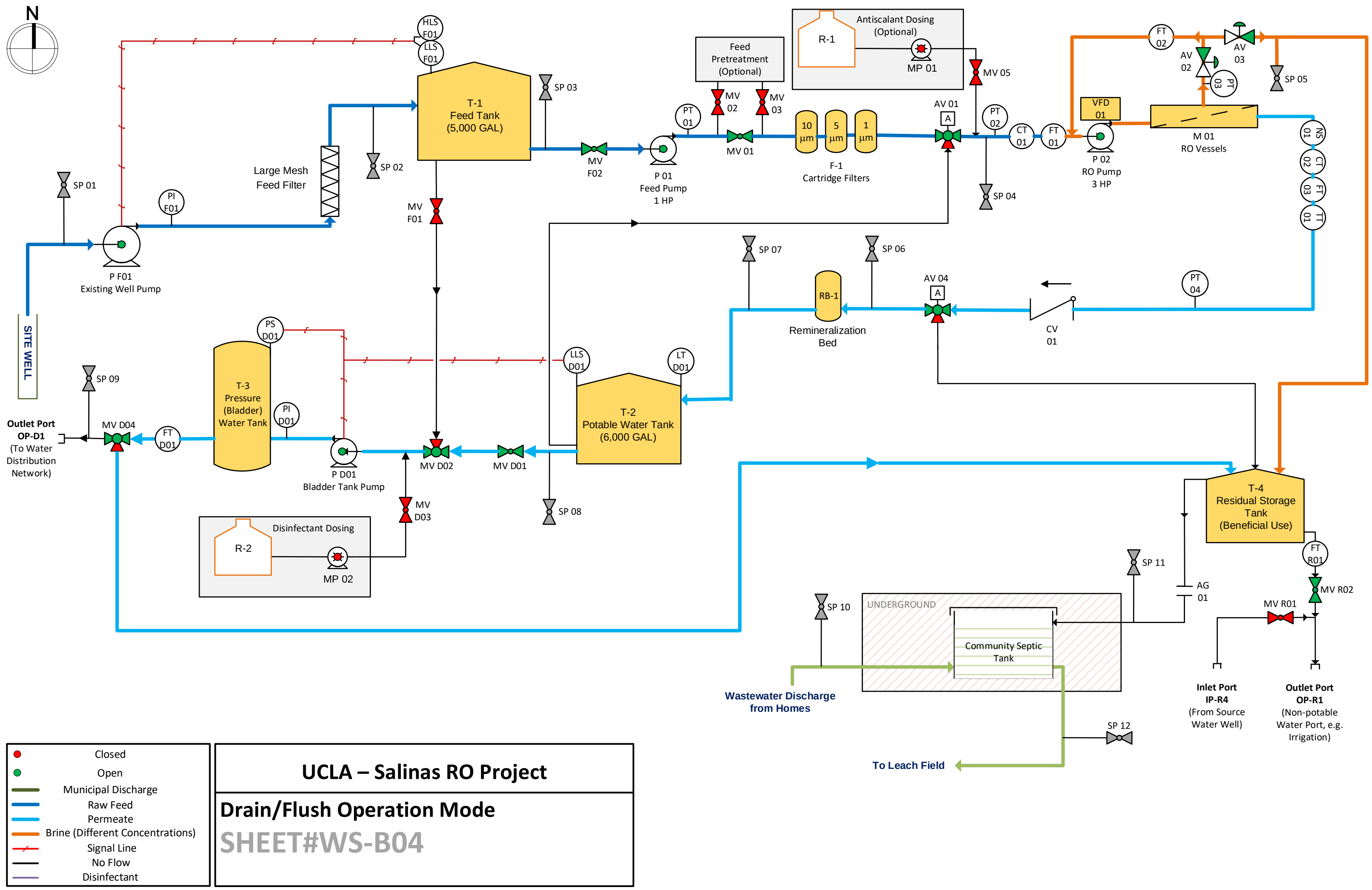

Figure B-4: *Process Flow Diagram (PFD) for the Drain/Flush mode of operation in the RO Systems for Nitrate Removal in Disadvantaged Remote Communities in the Salinas Valley project. Stream color-code is presented at the bottom left corner.*

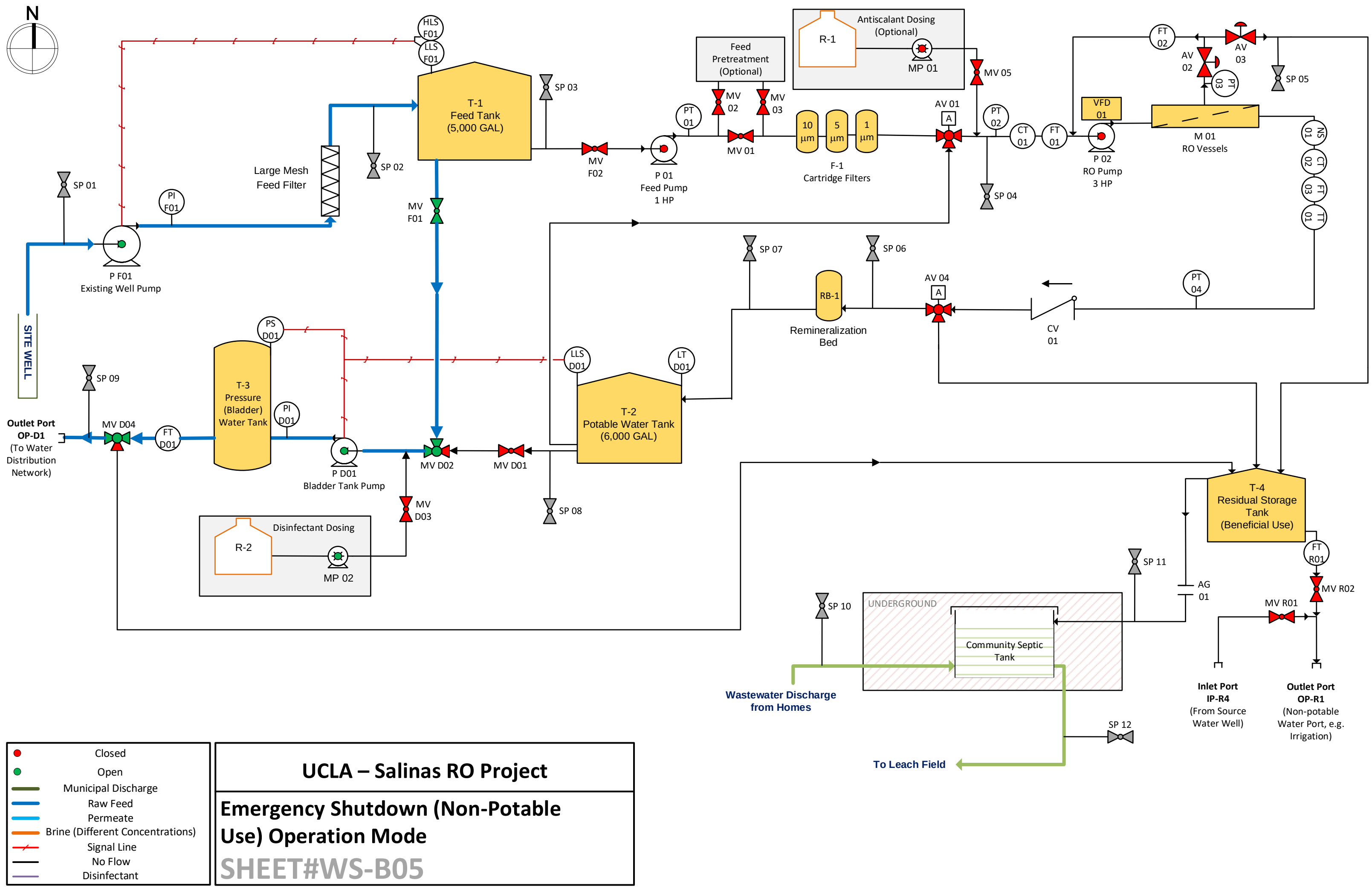

Figure B-5: *Process Flow Diagram (PFD) for the Emergency Shutdown (Non-Potable Use) mode of operation in the RO Systems for Nitrate Removal in Disadvantaged Remote Communities in the Salinas Valley project. Stream color-code is presented at the bottom left corner.*

The following are a list of modes of operation that will be implemented in the Salinas Valley Continuous High-Recovery RO Systems for Nitrate Removal in Disadvantaged Remote Communities project:

1- Routine operation
2- Fresh water flush operation
3- Consumable replacement operation
4- Commissioning period operation
5- Emergency shutdown (non-potable use) operation

Diagrams for previous moves of operation can be found in **Appendix B** (Figures **Fig.B-1** to **B-5**).

In addition, a summary list of design valve positioning during different modes of operation is found in Table 3-2.

Fresh Water Flush Operation

Periodic cleaning of membrane elements is to be carried via fresh water flush operation to about scale build-up and element fouling. The system feed pump (P 01), and the RO pump (P 02) are to be shut, and automated valve AV 01 is to be remotely re-configured to allow permeate water flow from the potable water tank (T-2) upon the activation of RO pump P 02. Upon activating P 02, fresh water will be drawn from T-2 and the RO unit membranes will be "flushed" with the flushing water being recycled, and ultimately disposed of into the residual storage tank which will drive the concentration of TDS inside the tank to decrease. With little to no water being produced into the permeate stream; it is deemed that the permeate stream is out of service, and its flow directed into the residual storage tank via the remotely-controlled valve AV 04. Driving the TDS concentration into the residual storage tank (T-4) will provide a wider range of beneficial use to its contents (e.g. cattle replenishment). Fresh water flush operational diagram can be found in **Appendix B, Fig. B-2**.

Emergency Shutdown (Non-Potable Use) Operation

Emergency shutdown procedures will be discussed expansively in Section 3.1.5, Operation & Maintenance Skeleton. However, in the event that one of the following conditions occur:

1- Power outage
2- Line disruption
3- System component failure that may obstruct overall system and site safe operation
4- Physical destruction to system components due to invasive anthropogenic behavior or natural disasters
5- Contamination outbreak

Then all system components will be remotely (and manually) taken offline. If preliminary diagnostics suggest that system repair may take time more than that of what the community's potable water reserves (T-2) permit, then a system bypass will be triggered. Untreated brakish water from the community well will bypass the now-offline RO system and continue to community distribution network. Brackish water will be drawn directly from the feed tank (T-1) through manual valve MV F01 (while shutting down MV F02, and everything beyond) and into manual valve MV D02. Water will be pumped by the bladder tank pump (P D01); activating the system's bypass line. Disinfectant dosing (R-1) will not take place in this process due to the condition that the water is in, and the hazard of forming trihalomethanes (THMs) with any organic matter that might be present in the system. After system repair, the system will proceed into Drain/Flush operational mode (Section 3.1.4.4). Emergency Shutdown (Non-Potable Use) event operational diagram can be found in **Appendix B, Fig. B-5**.

Table B-1[4]: valve positions for all modes of operation included in the water treatment system design[5].

		Operation				
Valves	**Location**	Routine	FWF	Con. Replacement	Drain/Flush	Emergency
MV F01	Maitnance/Bypass	X	X	X	X	O
MV F02	RO Feed	O	O	X	O	X
MV 01	RO Feed	O	O	X	O	X
MV 02	RO Feed	X	X	X	X	X
MV 03	RO Feed	X	X	X	X	X
MV 05	Antiscalant Dosing	X	X	X	X	X
MV D01	Post Treatment	O	O	O	O	X
MV D02	Post Treatment	O/X/O/NA	O/X/O/NA	O/X/O/NA	O/X/O/NA	O/O/X/NA
MV D03	Disinfectant Dosing	O	O	O	X	X
MV D04	Post Treatment	O/NA/O/X	O/NA/O/X	O/NA/O/X	X/NA/O/O	O/NA/O/X
MV R01	Residual Management	X	X	X	X	X
MV R02	Residual Management	O	O	O	O	X
AV 01	RO Feed	O/NA/O/X	X/NA/O/O	X	O/NA/O/X	X
AV 02	RO Concentrate	SO	SO	X	SO	X
AV 03	RO Residual	SO	SO	X	SO	X
AV 04	RO Permeate	O/NA/O/X	X/NA/O/O	X	O/NA/O/X	X

[4] Valve positioning for each operational valve and operational PFDs are indicated in **Appendix B:** Figures **B-1** to **B-5**. FWF = Fresh Water Flush, Con. = Consumable.

[5] Automated valve orientation is read clockwise: **West/North/East/South**. **O** = *Open*, **X** = *Closed*, **SO** = *Semi Open and Automated by Analog Input components (sensors)*, **NA** = *Not Applicable*.

Appendix C: Simulation Software Procedure

CSMPro5 is an RO Membrane System Design Software developed by Toray Chemical Korea Inc. The design software is programmed to offer a comprehensive simulation for an RO treatment process, and cost analysis based on water composition and operational parameter (permeate flow, recovery, recycle flow, membrane type, number of membranes, etc.) input by the user.

CSMPro5 is considered to be a viable tool in RO separation software analysis. CSMPro5 start-up page requires the user to define the water source as either Well Water, Surface Water, Sea Water or multiple other options that program-defined by their SDI (Silt Density Index) which applies a pre-built thermodynamic model to the simulation (e.g. Well Water SDI<3). The approach of predetermining the water's SDI allows the software to determine the fouling capacity of CSM membranes under high-pressure operation through plugging the input concentrations of metal ions into the preset thermodynamic model to calculate the resulting SDI of scaling-susceptible salts at the membrane surface.

Upon inputting mandatory (e.g. ion concentrations) and optional (e.g. Turbidity, TOC, pH) values into the water profile the user then can allocate design flow values into the program through the System tab. Within the System tab, the program requires the following steps associated with process specification definition before starting the simulation:

1- Define permeate flowrate (GPD)

2- Define recovery (%)

3- Define number of arrays

4- CSM Membrane Model

The user then inputs optional parameters based on the desired process:

5- Array to Array Recycle

6- Recycle Flow (GPD)

7- Permeate Blending (check box for more options)

The user then clicks Results, where the software will then initiate the simulation based of the specifications defined by the user. The Results section of the software is divided into three sections:

- Results scan: a detailed spreadsheet showing data associated with all process stream compositions and water quality reports, as well as basic RO process outputs (e.g. rejection, operating pressure, operating temperature) for the specific operation.
- Diagram: a simplified process flow diagram that shows the overall single-pass recovery in addition to a supporting table that shows all stream flowrates (GPD), TDS concentrations (mg/L), and pressure values (PSIG).
- Cost: calculates the cost associated with operating the process based membrane price ($/ea), vessel price ($/ea), and project life.

Appendix D: Simulation Supplementary Data/Results

Study DACs Site simulation (CSMPro5) results based on projected range of production:

Table D-1A: Bluerock View Apartments 2-element operation results.

Feed Flow (GPD)	2111.11	2166.67	2185.33	2222.22	2277.78	2333.33	2388.89	2444.44	2500.00	2666.67	2666.67	2666.67
Permeate Flow (GPD)	1900.00	1950.00	1966.80	2000.00	2050.00	2100.00	2150.00	2200.00	2250.00	2300.00	2350.00	2400.00
Recovery %	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Permeate Flux (gfd)	11.18	11.47	11.57	11.76	12.06	12.35	12.65	12.94	13.24	13.53	13.82	14.12
Recycle Ratio	2.05	1.99	1.98	1.94	1.90	1.85	1.81	1.77	1.73	1.62	1.62	1.62
Area (Ft2)	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00
Rejection (%)	91.83	92.02	92.08	92.19	92.36	92.52	92.68	92.82	92.97	93.10	93.23	93.35
NO3 Permeate Conc. (mg NO3/L)	27.02	26.40	26.20	25.81	25.26	24.72	24.21	23.73	23.26	22.82	22.39	21.98
TDS Permeate Conc. (mg/L)	118.18	115.48	114.61	112.92	110.47	108.14	105.91	103.78	101.74	99.78	97.91	96.11
pH	6.43	6.42	6.42	6.41	6.40	6.39	6.39	6.38	6.37	6.36	6.35	6.34
# of Elements	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
NO3 Initial (mg/L)	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00
TDS Initial (mg/L)	1446.27	1446.27	1446.27	1446.27	1446.27	1446.27	1446.27	1446.27	1446.27	1446.27	1446.27	1446.27
Nitrate Passage	0.15	0.15	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.12	0.12
Salt Passage	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Feed Press. (PSIG)	227.39	228.00	228.20	228.60	229.40	230.10	230.90	231.80	232.70	235.57	237.70	239.90
Conc. Pressure (PSIG)	225.86	226.50	226.70	227.00	227.80	228.50	229.30	230.20	231.00	233.90	236.00	238.20

units	GPD
Avg Demand	894
Design Flow (2*Av*1.1)	**1966.8**

Table D-1B: Bluerock View Apartments 3-element operation results.

Feed Flow (GPD)	2666.67	2888.89	3111.11	3333.33	3555.56	3777.78	4000.00	4222.22	4444.44	4666.67
Permeate Flow (GPD)	2400.00	2600.00	2800.00	3000.00	3200.00	3400.00	3600.00	3800.00	4000.00	4200.00
Recovery %	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Permeate Flux (gfd)	9.41	10.20	10.98	11.76	12.55	13.33	14.12	14.90	15.69	16.47
Recycle Ratio	1.62	1.50	1.39	1.30	1.22	1.14	1.08	1.02	0.97	0.93
Area (Ft2)	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00
Rejection (%)	90.84	91.47	92.10	92.73	93.29	93.37	94.12	94.52	94.80	95.09
NO3 Permeate Conc. (mg NO3/L)	30.23	28.15	26.02	23.86	21.97	20.52	19.22	17.88	16.97	16.03
TDS Permeate Conc. (mg/L)	132.49	123.35	114.24	105.14	97.09	90.74	85.06	79.25	75.21	71.06
pH	6.48	6.45	6.42	6.38	6.35	6.32	6.29	6.26	6.24	6.21
# of Elements	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
NO3 Initial (mg/L)	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00
TDS Initial (mg/L)	1386.85	1386.85	1386.85	1386.85	1386.85	1386.85	1386.85	1386.85	1386.85	1386.85
Nitrate Passage	0.17	0.16	0.14	0.13	0.12	0.11	0.11	0.10	0.09	0.09
Salt Passage	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.05	0.05
Feed Press. (PSIG)	201.71	203.90	206.40	206.60	207.30	209.20	209.90	211.90	214.00	216.90
Conc. Pressure (PSIG)	199.20	201.30	203.70	203.90	204.50	206.30	206.90	208.80	210.80	213.60
units	GPD									
Avg Demand	894									
Design Flow (2*Av*1.1)	**1966.8**									

Table D-1C: Santa Teresa Farms Park 3-element operation results.

Feed Flow (GPD)	3000.00	3222.22	3412.22	3666.67	3888.89	4111.11	4333.33	4555.56
Permeate Flow (GPD)	2700.00	2900.00	3071.00	3300.00	3500.00	3700.00	3900.00	4100.00
Recovery %	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Permeate Flux (gfd)	10.59	11.37	12.04	12.94	13.73	14.51	15.29	16.08
Recycle Ratio	1.44	1.34	1.27	1.18	1.11	1.05	1.00	0.95
Area (Ft2)	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00
Rejection (%)	91.91	92.58	93.06	93.60	94.05	94.37	94.71	95.02
NO3 Permeate Conc. (mg NO3/L)	6.69	6.11	5.70	5.24	4.86	4.60	4.32	4.06
TDS Permeate Conc. (mg/L)	45.38	41.62	38.95	35.90	33.37	31.57	29.66	27.92
pH	6.51	6.47	6.44	6.41	6.38	6.35	6.33	6.30
# of Elements	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
NO3 Initial (mg/L)	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00
TDS Initial (mg/L)	561.09	561.09	561.09	561.09	561.09	561.09	561.09	561.09
Nitrate Passage	0.15	0.14	0.13	0.12	0.11	0.10	0.10	0.09
Salt Passage	0.08	0.07	0.07	0.06	0.06	0.06	0.05	0.05
Feed Press. (PSIG)	128.90	131.70	134.40	138.25	141.54	145.60	149.29	153.00
Conc. Pressure (PSIG)	126.24	129.00	131.50	135.30	138.50	142.50	156.06	149.70

units	GPD
Avg Demand	1396
Design Flow (2*Av*1.1)	**3071.2**

Table D-1D: Pryor Farms well "6" single pass 4-element operation results.

Feed Flow (GPD)	5944.44	6000.00	6055.56	6111.11	6166.67	6222.22	6277.78	6333.33	6388.89	6444.44
Permeate Flow (GPD)	5350.00	5400.00	5450.00	5500.00	5550.00	5600.00	5650.00	5700.00	5750.00	5800.00
Recovery %	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Permeate Flux (gfd)	15.74	15.88	16.03	16.18	16.32	16.47	16.62	16.76	16.91	17.06
Recycle Raio	0.73	0.72	0.71	0.71	0.70	0.69	0.69	0.68	0.68	0.67
Area (Ft2)	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00
Rejection (%)	95.73	95.78	95.82	95.89	95.93	95.95	96.01	96.05	96.09	96.15
NO3 Permeate Conc. (mg NO3/L)	8.61	8.52	8.43	8.30	8.22	8.14	8.06	7.98	7.92	7.78
TDS Permeate Conc. (mg/L)	53.62	53.06	52.52	51.70	51.18	50.66	50.15	49.65	49.16	48.83
pH	6.19	6.19	6.18	6.17	6.17	6.17	6.16	6.16	6.15	6.15
# of Elements	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
NO3 Initial (mg/L)	101.70	101.70	101.70	101.70	101.70	101.70	101.70	101.70	101.70	101.70
TDS Initial (mg/L)	1257.00	1257.00	1257.00	1257.00	1257.00	1257.00	1257.00	1257.00	1257.00	1257.00
Nitrate Passage	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Salt Passage	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Feed Press. (PSIG)	190.20	190.84	191.50	191.65	192.30	192.90	193.55	194.20	194.83	194.95
Conc. Pressure (PSIG)	185.00	185.60	186.20	186.35	187.00	187.50	188.20	188.80	189.36	189.44

units	GPD
Avg Demand	2546
Peak Demand	3997
Design Flow (2*Av*1.1)	**5601.2**

Table D-1E: Pryor Farms well "L" (decommissioned from operation) two-pass, 10-element operation results.

1ST PASS									
Raw Feed (GPD)	5880	5997	6113	6230	6347	6463	6580	6697	6813
Feed Flow (GPD)	8400	8567	8733	8900	9067	9233	9400	9567	9733
1st Pass Permeate Flow (GPD)	7560	7710	7860	8010	8160	8310	8460	8610	8760
1st Pass Permeate Flux (gfd)	14.82	15.12	15.41	15.71	16.00	16.29	16.59	16.88	17.18
1st Pass Recycle Ratio	0.51	0.50	0.49	0.49	0.48	0.47	0.46	0.45	0.44
Permeate Blending (GPD)	2520	2570	2620	2670	2720	2770	2820	2870	2920
1st Pass Rejection (%)	96.6	96.7	96.78	96.85	96.93	97	97.06	97.13	97.19
NO3 permeate conc (mg NO3/L)	21.93	21.3	20.79	20.3	19.83	19.38	18.95	18.53	18.13
TDS permeate conc (mg/L)	51.72	50.22	49	47.85	46.75	45.68	44.66	43.67	42.72
pH	6.03	6.02	6.01	6	5.99	5.98	5.97	5.96	5.95
1st Feed Press. (PSIG)	163.88	165	166.34	167.7	169.1	170.6	172	173.5	174.9
1st Conc. Press. (PSIG)	153.72	154.6	155.81	157	158.3	159.5	160.8	162	163.3
2ND PASS									
2nd Pass Permeate Flow (GPD)	2520	2570	2620	2670	2720	2770	2820	2870	2920
2nd Pass Permeate Flux (gfd)	7.41	7.56	7.71	7.85	8.00	8.15	8.29	8.44	8.59
2nd Pass Recycle Ratio	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2nd Pass Rejection (%)	97.3	97.37	97.41	97.45	97.5	97.53	97.56	97.6	97.64
NO3 permeate conc (mg NO3/L)	0.76	0.73	0.7	0.67	0.64	0.61	0.59	0.57	0.55
TDS permeate conc (mg/L)	1.38	1.32	1.27	1.22	1.17	1.13	1.09	1.05	1.01
pH	4.49	4.47	4.45	4.43	4.41	4.4	4.38	4.36	4.35
2nd Feed Press. (PSIG)	47.16	48.12	49.1	50.1	51	52	52.9	53.9	54.9
2nd Conc. Press. (PSIG)	45.46	46.4	47.27	48.2	49.1	50	50.9	51.8	52.7
POST-BLENDING WATER									
NO3 permeate conc (mg NO3/L)	11.345	11.015	10.745	10.485	10.235	9.995	9.77	9.55	9.34
TDS permeate conc (mg/L)	26.55	25.77	25.135	24.535	23.96	23.405	22.875	22.36	21.865
Permeate Production Flow (GPD)	5040	5140	5240	5340	5440	5540	5640	5740	5840

Table D-1F: Pryor Farms well "L" (decommissioned from operation) two-pass, 10-element operation results continuation.

Avg demand (GPD)	**2520**
Peak demand (GPD)	**3594**
Design Production Flow (GPD)	**5440**
Overall recovery	**90.00**
TDS Initial (mg/L)	**1520**
NO_3^- Initial (mg/L)	**389.7**

1ST PASS ELEMENT COUNT
6
2ND PASS ELEMENT COUNT
4
MEMBRANE TYPE
CSM RE4040-BE
MEMBRANE AREA (Ft^2)
85

Study DACs Site maximum allowable feed concentration simulation (CSMPro5) results until reaching EPA MCL (45 mg/L as NO_3^-) based on design production capacity:

Table D-2A-B: Bluerock View Apartments (left) and Santa Teresa Farms Park (right) maximum allowable nitrate feed concentration (mg/L as NO_3^-) simulation results at design capacity of 1966 GPD (2-E) & 3070 GPD (3-E) respectively before producing a permeate with the EPA MCL for nitrate (45 mg/L as NO_3^-)

Feed nitrate conc. (mg/L as NO_3^-)	Permeate nitrate conc (mg/L as NO_3^-)
30	4.35
50	7.26
70	10.16
90	13.07
110	15.99
130	18.9
150	21.82
170	24.75
190	27.67
210	30.6
230	33.53
250	36.51
270	39.41
290	42.35
310	45.29

Feed nitrate conc. (mg/L as NO_3^-)	Permeate nitrate conc (mg/L as NO_3^-)
30	3.79
60	7.59
90	11.36
120	15.14
150	18.9
180	22.66
210	26.69
240	30.48
270	34.25
300	38
330	41.75
360	45.29

Table D-2C: Pryor Farms well "6" maximum allowable nitrate feed concentration (mg/L as NO_3^-) simulation results at design capacity of 5600 GPD (3-E) before producing a permeate with the EPA MCL for nitrate (45 mg/L as NO_3^-).

Feed nitrate conc. (mg/L as NO_3^-)	Permeate nitrate conc (mg/L as NO_3^-)
20	1.6
60	4.79
100	8
140	11.2
180	14.44
220	17.68
260	20.92
300	24.09
340	27.33
380	30.59
420	33.85
460	37.12
500	40.4
540	43.55
580	46.23

Study DACs Site maximum allowable feed concentration simulation (CSMPro5) results until reaching "Safe Point" limit of 25 mg/L as NO_3^- in the permeate based on design range of production:

Table D-3A: Bluerock View Apartments DAC maximum allowable nitrate feed concentration (mg/L as NO_3^-) simulation results at design range of production (1,900 – 2,400 GPD) before producing a permeate with the design "Safe Point" limit for nitrate (20 mg/L as NO_3^-).

Feed nitrate conc. (mg/L as NO_3^-)	Permeate nitrate conc (mg/L as NO_3^-)	Permeate flowrate (GPD)
135	20.14	1900
138	20.12	1950
141	20.1	2000
144	20.08	2050
147	20.06	2100
150	20.05	2150
153	20.04	2200
156	20.03	2250
159	20.02	2300
162	20.02	2350
165	20.02	2400

Table D-3B: Santa Teresa Farms Park DAC maximum allowable nitrate feed concentration (mg/L as NO_3^-) simulation results at design range of production (2,700 – 4,100 GPD) before producing a permeate with the design "Safe Point" limit for nitrate (20 mg/L as NO_3^-)

Feed nitrate conc. (mg/L as NO_3^-)	Permeate nitrate conc (mg/L as NO_3^-)	Permeate flowrate (GPD)
136	20.01	2700
147	19.96	2900
161	20.03	3100
172	20.01	3300
184	20	3500
198	20.01	3700
209	20.05	3900
222	20.07	4100

Table D-3C: Pryor Farms DAC well "6" maximum allowable nitrate feed concentration (mg/L as NO_3^-) simulation results at design range of production (5,350 – 5,800GPD) before producing a permeate with the design "Safe Point" limit for nitrate (20 mg/L as NO_3^-)

Feed nitrate conc. (mg/L as NO_3^-)	Permeate nitrate conc (mg/L as NO_3^-)	Permeate flowrate (GPD)
237	20.05	5350
240	20.01	5400
242.5	19.98	5450
245	20.02	5500
247.5	20.07	5550
250	20.11	5600
252.5	20.08	5650
255	19.94	5700
258	19.98	5750
261	20.02	5800

Study DACs Site nitrate-salt passage correlation simulation (CSMPro5) results

Table D-4A: Data for the Bluerock View Apartments DAC simulations at recovery settings of 50, 70, and 90%, feed NO3 concentrations of 100, 180, 260 mg/L as NO_3^-, and flux range of operation of 10-15 gfd

10 gfd	1700GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	180	260	100	180	260	100	180	260
TDS Feed (mg/L)	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18
Flux	10	10	10	10	10	10	10	10	10
NO3 In perm. (mg/L)	16.44	29.4	42.19	5.46	9.83	14.21	3.21	5.79	8.37
TDS In perm. (mg/L)	124.38	138.97	153.37	41.41	46.6	51.79	24.32	27.38	30.45
NO3 Passage	0.1644	0.163333	0.162269	0.0546	0.054611	0.054654	0.0321	0.032167	0.032192
Salt Passage	0.084738	0.088095	0.090903	0.028212	0.02954	0.030696	0.016569	0.017357	0.018048

11 gfd	1870GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	180	260	100	180	260	100	180	260
TDS Feed (mg/L)	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18
Flux	11	11	11	11	11	11	11	11	11
NO3 In perm. (mg/L)	15.1	27.02	38.78	4.96	8.87	12.8	2.91	5.25	7.59
TDS In perm. (mg/L)	114.25	127.7	140.98	37.62	41.97	46.66	22.05	24.83	27.61
NO3 Passage	0.151	0.150111	0.149154	0.0496	0.049278	0.049231	0.0291	0.029167	0.029192
Salt Passage	0.077837	0.080951	0.08356	0.02563	0.026605	0.027656	0.015022	0.01574	0.016365

12 gfd	2040GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	180	260	100	180	260	100	180	260
TDS Feed (mg/L)	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18
Flux	12	12	12	12	12	12	12	12	12
NO3 In perm. (mg/L)	13.98	25.01	35.92	4.51	8.12	11.74	2.66	4.8	6.94
TDS In perm. (mg/L)	105.74	118.22	130.56	34.17	38.47	42.77	20.16	22.7	25.24
NO3 Passage	0.1398	0.138944	0.138154	0.0451	0.045111	0.045154	0.0266	0.026667	0.026692
Salt Passage	0.072039	0.074941	0.077384	0.023279	0.024387	0.02535	0.013735	0.01439	0.01496

13 gfd	2210GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	180	260	100	180	260	100	180	260
TDS Feed (mg/L)	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18
Flux	13	13	13	13	13	13	13	13	13
NO3 In perm. (mg/L)	13.02	23.31	33.48	4.12	7.42	10.74	2.45	4.42	6.39
TDS In perm. (mg/L)	98.49	110.15	121.68	31.25	35.18	39.12	18.56	20.89	23.23
NO3 Passage	0.1302	0.1295	0.128769	0.0412	0.041222	0.041308	0.0245	0.024556	0.024577
Salt Passage	0.0671	0.069826	0.07212	0.02129	0.022301	0.023187	0.012645	0.013242	0.013769

14 gfd	2380GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	180	260	100	180	260	100	180	260
TDS Feed (mg/L)	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18
Flux	14	14	14	14	14	14	14	14	14

NO3 In perm. (mg/L)	12.2	21.84	31.37	3.82	6.88	9.95	2.27	4.1	5.93
TDS In perm. (mg/L)	92.25	103.2	114.03	28.94	32.59	36.24	17.18	19.34	21.51
NO3 Passage	0.122	0.121333	0.120654	0.0382	0.038222	0.038269	0.0227	0.022778	0.022808
Salt Passage	0.062848	0.06542	0.067586	0.019716	0.020659	0.02148	0.011704	0.01226	0.012749

15 gfd	2550GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	180	260	100	180	260	100	180	260
TDS Feed (mg/L)	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18	1467.82	1577.5	1687.18
Flux	15	15	15	15	15	15	15	15	15
NO3 In perm. (mg/L)	11.48	20.56	29.54	3.55	6.41	9.27	2.11	3.81	5.51
TDS In perm. (mg/L)	86.82	97.14	107.36	26.94	30.33	33.74	15.99	18	20.02
NO3 Passage	0.1148	0.114222	0.113615	0.0355	0.035611	0.035654	0.0211	0.021167	0.021192
Salt Passage	0.059149	0.061578	0.063633	0.018354	0.019227	0.019998	0.010894	0.01141	0.011866

Table D-4B: Data for the Santa Teresa Farms DAC simulations at recovery settings of 50, 70, and 90%, feed NO3 concentrations of 20, 60, 100 mg/L as NO_3^-, and flux range of operation of 10-15 gfd

10 gfd	2550GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	20	60	100	20	60	100	20	60	100
TDS Feed (mg/L)	539.27	594.1	648.95	539.27	594.1	648.95	539.27	594.1	648.95
Flux	10	10	10	10	10	10	10	10	10
NO3 In perm. (mg/L)	3.18	9.51	15.81	1	3.01	5.03	0.6	1.81	3.02
TDS In perm. (mg/L)	44.67	52.04	59.37	14.1	16.49	18.89	8.41	9.83	11.26
NO3 Passage	0.159	0.1585	0.1581	0.05	0.050167	0.0503	0.03	0.030167	0.0302
Salt Passage	0.082834	0.087595	0.091486	0.026146	0.027756	0.029109	0.015595	0.016546	0.017351

11 gfd	2805GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	20	60	100	20	60	100	20	60	100
TDS Feed (mg/L)	539.27	594.1	648.95	539.27	594.1	648.95	539.27	594.1	648.95
Flux	11	11	11	11	11	11	11	11	11
NO3 In perm. (mg/L)	2.83	8.48	14.11	0.91	2.74	4.57	0.54	1.63	2.73
TDS In perm. (mg/L)	39.98	46.58	53.15	12.74	14.91	17	7.61	8.9	10.19
NO3 Passage	0.1415	0.141333	0.1411	0.0455	0.045667	0.0457	0.027	0.027167	0.0273
Salt Passage	0.074137	0.078404	0.081902	0.023625	0.025097	0.026196	0.014112	0.014981	0.015702

12 gfd	3060GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	20	60	100	20	60	100	20	60	100
TDS Feed (mg/L)	539.27	594.1	648.95	539.27	594.1	648.95	539.27	594.1	648.95
Flux	12	12	12	12	12	12	12	12	12

NO3 In perm. (mg/L)	2.54	7.61	12.68	0.83	2.48	4.13	0.49	1.49	2.49
TDS In perm. (mg/L)	35.98	42.03	47.89	11.61	13.56	15.44	6.91	8.12	9.3
NO3 Passage	0.127	0.126833	0.1268	0.0415	0.041333	0.0413	0.0245	0.024833	0.0249
Salt Passage	0.06672	0.070746	0.073796	0.021529	0.022824	0.023792	0.012814	0.013668	0.014331

13 gfd	4420								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	200	400	100	200	400	100	200	400
TDS Feed (mg/L)	1249.48	1349.49	1540.5	1249.48	1349.49	1540.5	1249.48	1349.49	1540.5
Flux	13	13	13	13	13	13	13	13	13
NO3 In perm. (mg/L)	10.52	21.07	42.37	3.58	7.13	14.29	2.21	4.42	8.86
TDS In perm. (mg/L)	65.1	75.73	97.26	21.75	25.2	32.41	13.35	15.58	20.04
NO3 Passage	0.1052	0.10535	0.105925	0.0358	0.03565	0.035725	0.0221	0.0221	0.02215
Salt Passage	0.052102	0.056117	0.063135	0.017407	0.018674	0.021039	0.010684	0.011545	0.013009
Feed Pressure	178.57	186.02	201.12	119.39	121.92	127.45	110.45	112.38	116.25
Concentrate Pressure	174.02	181.48	196.61	113.09	115.62	121.16	100.72	102.65	106.52

14 gfd	4760								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	200	400	100	200	400	100	200	400
TDS Feed (mg/L)	1249.48	1349.49	1540.5	1249.48	1349.49	1540.5	1249.48	1349.49	1540.5
Flux	14	14	14	14	14	14	14	14	14
NO3 In perm. (mg/L)	9.7	19.26	38.77	3.3	6.57	13.18	2.04	4.09	8.19
TDS In perm. (mg/L)	59.96	69.17	88.98	20.04	23.22	29.87	12.34	14.39	18.51
NO3 Passage	0.097	0.0963	0.096925	0.033	0.03285	0.03295	0.0204	0.02045	0.020475
Salt Passage	0.047988	0.051256	0.05776	0.016039	0.017207	0.01939	0.009876	0.010663	0.012016
Feed Pressure	182.35	188.79	203.53	125.06	127.53	132.93	116.72	118.61	122.4
Concentrate Pressure	177.57	184.02	198.8	118.36	120.83	126.24	106.22	108.11	111.91

15 gfd	5100								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	200	400	100	200	400	100	200	400
TDS Feed (mg/L)	1249.48	1349.49	1540.5	1249.48	1349.49	1540.5	1249.48	1349.49	1540.5
Flux	15	15	15	15	15	15	15	15	15
NO3 In perm. (mg/L)	8.89	17.82	35.93	3.06	6.13	12.22	1.9	3.8	7.61
TDS In perm. (mg/L)	54.9	63.96	82.41	18.56	21.66	27.68	11.46	13.37	17.2
NO3 Passage	0.0889	0.0891	0.089825	0.0306	0.03065	0.03055	0.019	0.019	0.019025
Salt Passage	0.043938	0.047396	0.053496	0.014854	0.016051	0.017968	0.009172	0.009907	0.011165

Table D-4C: Data for the Pryor Farms DAC simulations at recovery settings of 50, 70, and 90%, feed NO3 concentrations of 100, 200, and 400 mg/L as NO_3^-, and flux range of operation of 10-15 gfd

10 gfd	3400GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	200	400	100	200	400	100	200	400
TDS Feed (mg/L)	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99
Flux	10	10	10	10	10	10	10	10	10
NO3 In perm. (mg/L)	14.4	28.94	58.2	4.76	9.47	19.02	2.92	5.84	11.72
TDS In perm. (mg/L)	87.26	104.62	139.17	28.5	33.94	45.3	17.35	20.83	27.81
NO3 Passage	0.144	0.1447	0.1455	0.0476	0.04735	0.04755	0.0292	0.0292	0.0293
Salt Passage	0.071077	0.076657	0.084912	0.023215	0.024868	0.027639	0.014132	0.015263	0.016968

11 gfd	3740GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	200	400	100	200	400	100	200	400
TDS Feed (mg/L)	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99
Flux	11	11	11	11	11	11	11	11	11
NO3 In perm. (mg/L)	12.86	25.83	52.11	4.3	8.55	17.16	2.63	5.28	10.59
TDS In perm. (mg/L)	78.1	93.57	124.92	25.68	30.59	40.84	15.67	18.81	25.12
NO3 Passage	0.1286	0.12915	0.130275	0.0430	0.04275	0.0429	0.0263	0.0264	0.026475
Salt Passage	0.063616	0.068561	0.076218	0.020918	0.022414	0.024918	0.012764	0.013782	0.015327

12 gfd	4080GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50

NO3 Feed (mg/L)	100	200	400	100	200	400	100	200	400
TDS Feed (mg/L)	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99
Flux	12	12	12	12	12	12	12	12	12
NO3 In perm. (mg/L)	11.6	23.2	46.53	3.91	7.78	15.61	2.4	4.81	9.66
TDS In perm. (mg/L)	70.5	84.14	111.85	23.33	27.81	37.14	14.28	17.15	22.9
NO3 Passage	0.116	0.116	0.116325	0.0391	0.0389	0.039025	0.024	0.02405	0.02415
Salt Passage	0.057425	0.061651	0.068243	0.019003	0.020377	0.02266	0.011632	0.012566	0.013972

13 gfd	4420GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	200	400	100	200	400	100	200	400
TDS Feed (mg/L)	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99
Flux	13	13	13	13	13	13	13	13	13
NO3 In perm. (mg/L)	10.56	21.2	42.54	3.58	7.13	14.31	2.21	4.42	8.87
TDS In perm. (mg/L)	64.22	76.95	102.26	21.36	25.47	34.01	13.11	15.74	21.02
NO3 Passage	0.1056	0.106	0.10635	0.0358	0.03565	0.035775	0.0221	0.0221	0.022175
Salt Passage	0.05231	0.056383	0.062392	0.017399	0.018662	0.020751	0.010679	0.011533	0.012825

14 gfd	4760GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	200	400	100	200	400	100	200	400
TDS Feed (mg/L)	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99
Flux	14	14	14	14	14	14	14	14	14
NO3 In perm. (mg/L)	9.63	19.44	39.11	3.3	6.57	13.19	2.04	4.09	8.2
TDS In perm. (mg/L)	58.52	70.56	93.99	19.68	23.47	31.35	12.12	14.55	19.42
NO3 Passage	0.0963	0.0972	0.097775	0.033	0.03285	0.032975	0.0204	0.02045	0.0205
Salt Passage	0.047667	0.051701	0.057346	0.01603	0.017197	0.019128	0.009872	0.010661	0.011849

15 gfd	5100GPD								
Recovery (%)	90	90	90	70	70	70	50	50	50
NO3 Feed (mg/L)	100	200	400	100	200	400	100	200	400
TDS Feed (mg/L)	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99	1227.68	1364.78	1638.99
Flux	15	15	15	15	15	15	15	15	15
NO3 In perm. (mg/L)	8.88	17.82	36.1	3.06	6.12	12.23	1.9	3.8	7.62
TDS In perm. (mg/L)	53.92	65.07	86.81	18.23	21.89	29.05	11.26	13.51	18.04
NO3 Passage	0.0888	0.0891	0.09025	0.0306	0.0306	0.030575	0.019	0.019	0.01905
Salt Passage	0.04392	0.047678	0.052966	0.014849	0.016039	0.017724	0.009172	0.009899	0.011007

Study DACs Site nitrate-salt passage correlation simulation (CSMPro5) figures for 50 & 70% recovery operation (90% operation is found in section 5.5)

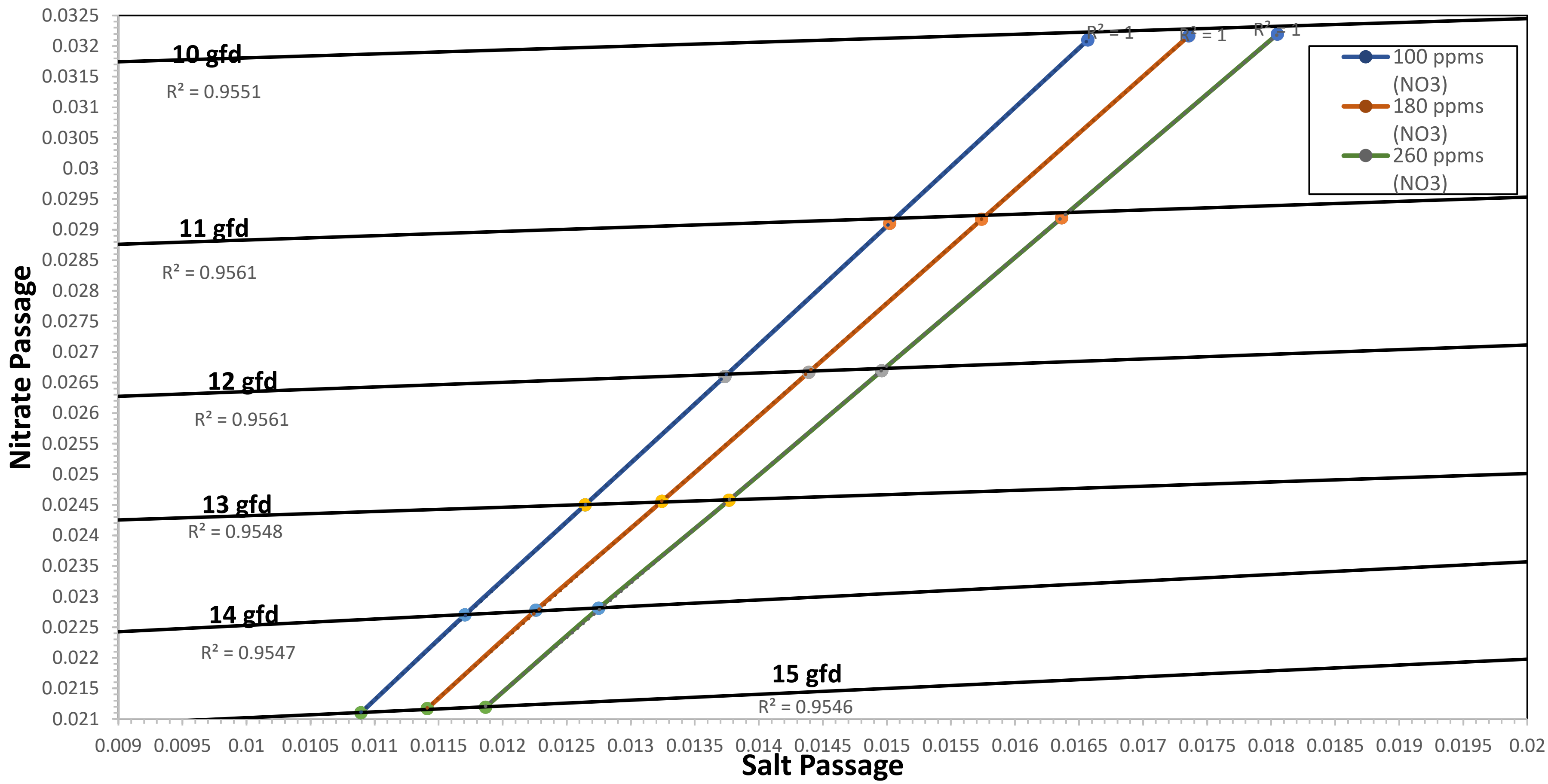

Figure D-4A: Blue Rock View Apartments site-specific salt passage-nitrate passage correlation of different feed nitrate concentrations (100, 180, and 260 mg/L as NO_3^-) simulated at **50%** recovery operation. Isoflux lines are indicated by the color black, followed by their coefficient of determination value. Current nitrate levels measured at the ground water well are 180 mg/L as NO_3^-.

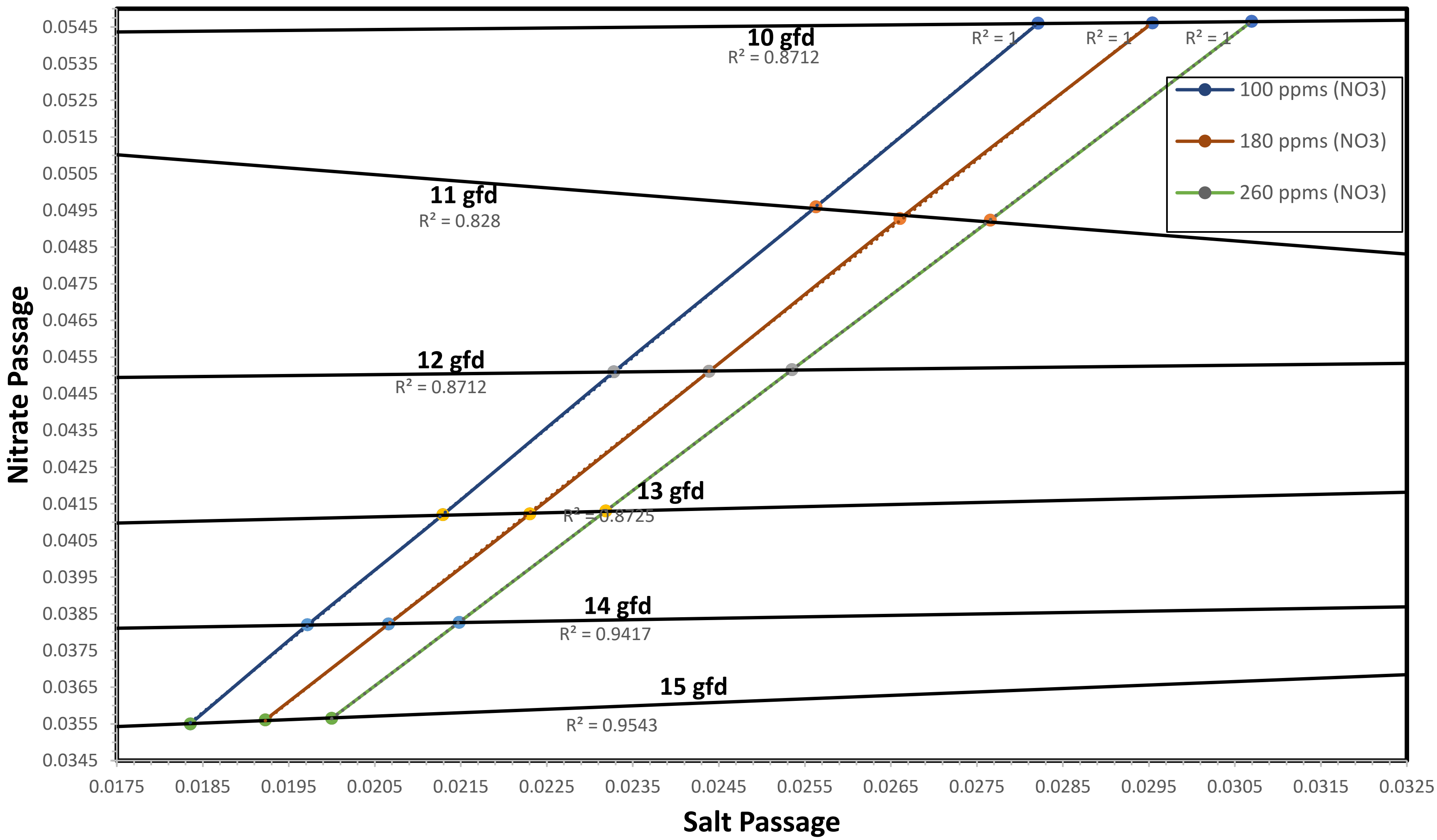

Figure D-4B: Blue Rock View Apartments site-specific salt passage-nitrate passage correlation of different feed nitrate concentrations (100, 180, and 260 mg/L as NO3-) simulated at **70%** recovery operation. Isoflux lines are indicated by the color black, followed by their coefficient of determination value. Current nitrate levels measured at the ground water well are 180 mg/L as NO_3^-.

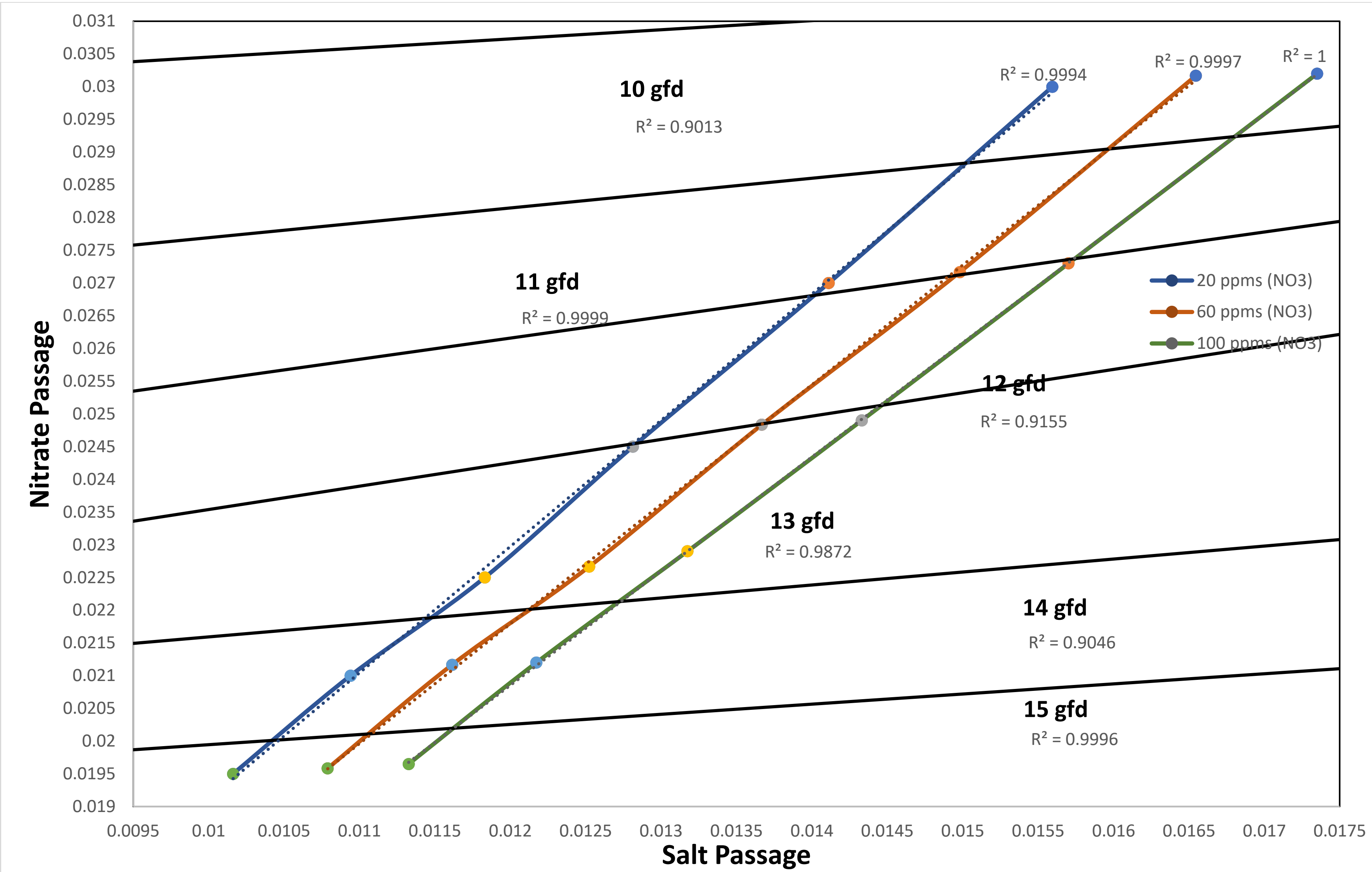

Figure D-4C: Santa Teresa Farms Park site-specific salt passage-nitrate passage correlation of different feed nitrate concentrations (20, 60, and 100 mg/L as NO3-) simulated at **50%** recovery operation. Isoflux lines are indicated by the color black, followed by their coefficient of determination value. Current nitrate levels measured at the ground water well are 45 mg/L as NO_3^-.

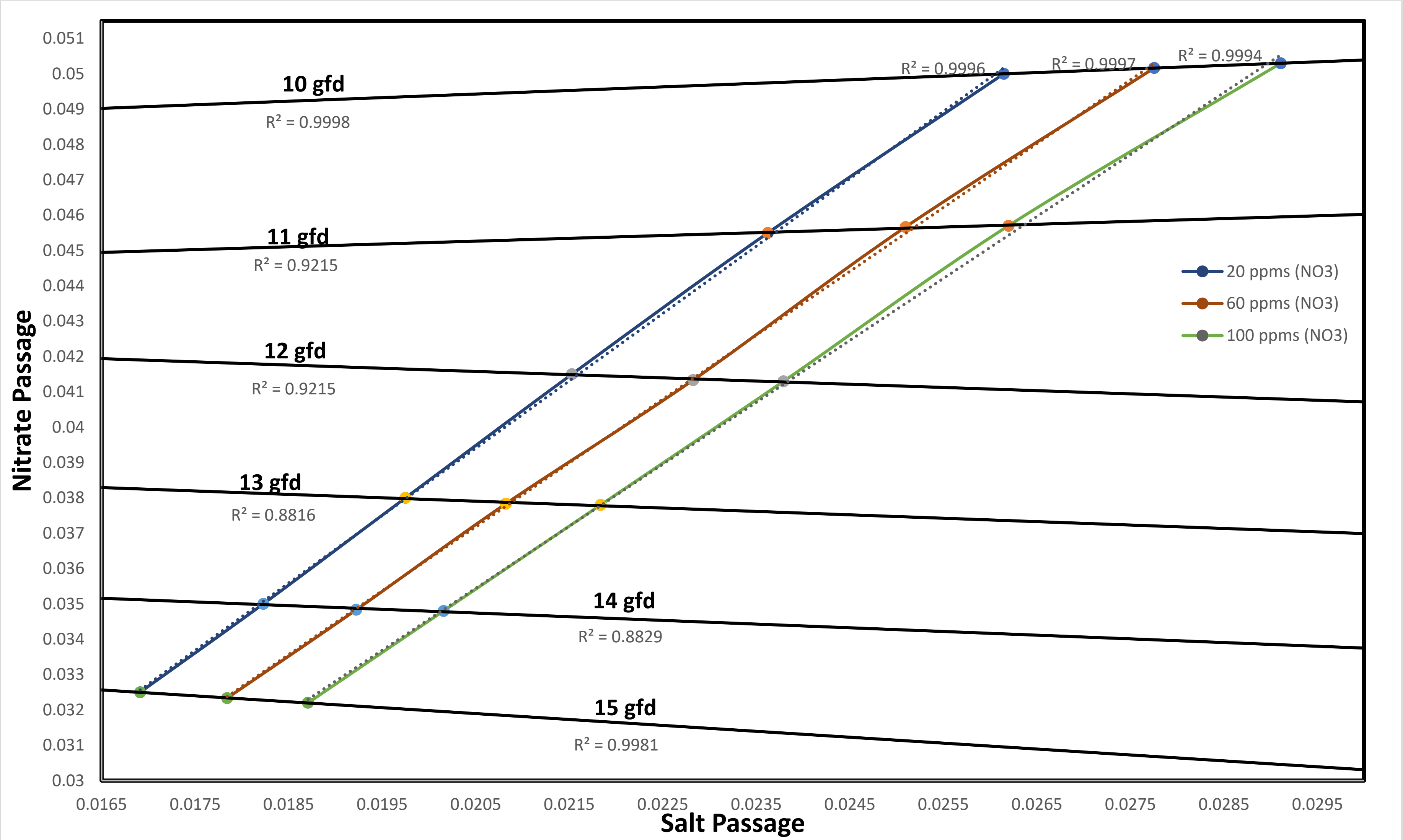

Figure D-4D: Santa Teresa Farms Park site-specific salt passage-nitrate passage correlation of different feed nitrate concentrations (20, 60, and 100 mg/L as NO3-) simulated at **70%** recovery operation. Isoflux lines are indicated by the color black, followed by their coefficient of determination value. Current nitrate levels measured at the ground water well are 45 mg/L as NO_3^-.

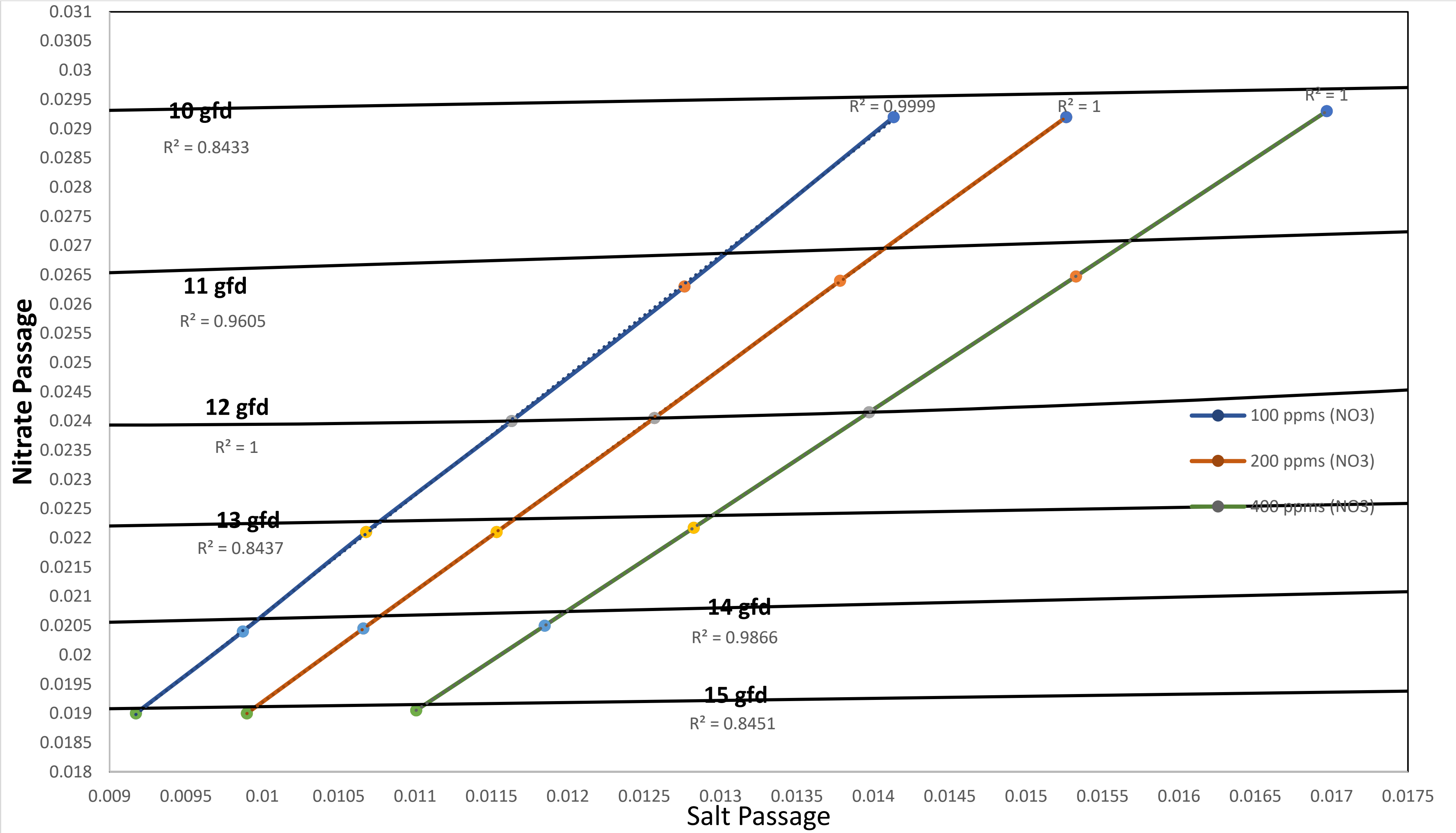

Figure D-4E: Pryor Farms well "6" site-specific salt passage-nitrate passage correlation of different feed nitrate concentrations (100, 200, and 400 mg/L as NO3-) simulated at **50%** recovery operation. Isoflux lines are indicated by the color black, followed by their coefficient of determination value. Current nitrate levels measured at the ground water well are 101.7 mg/L as NO_3^-.

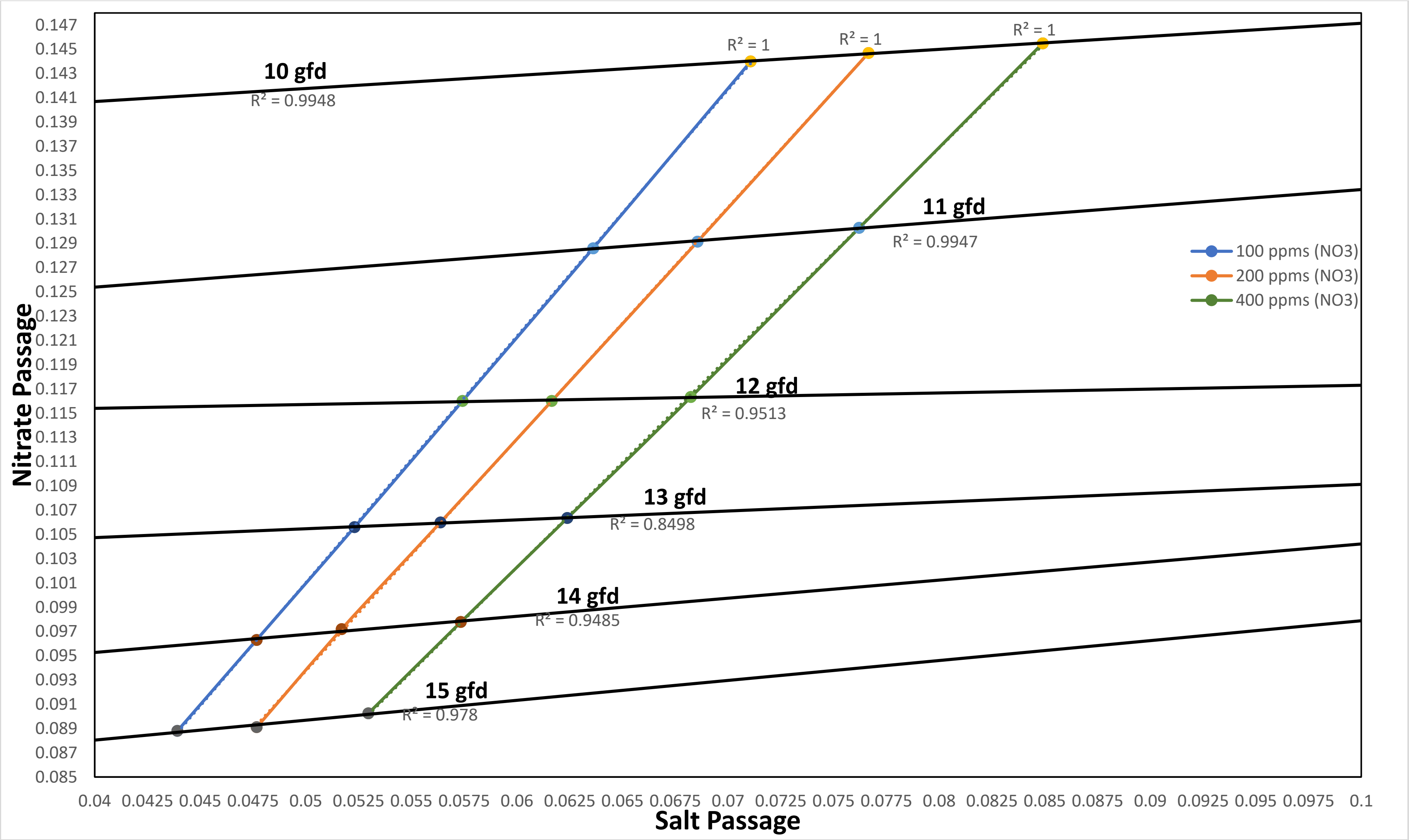

Figure D-4F: Pryor Farms well "6" site-specific salt passage-nitrate passage correlation of different feed nitrate concentrations (100, 200, and 400 mg/L as NO3-) simulated at **70%** recovery operation. Isoflux lines are indicated by the color black, followed by their coefficient of determination value. Current nitrate levels measured at the ground water well are 101.7 mg/L as NO_3^-.

Appendix E: Site Topography & Information

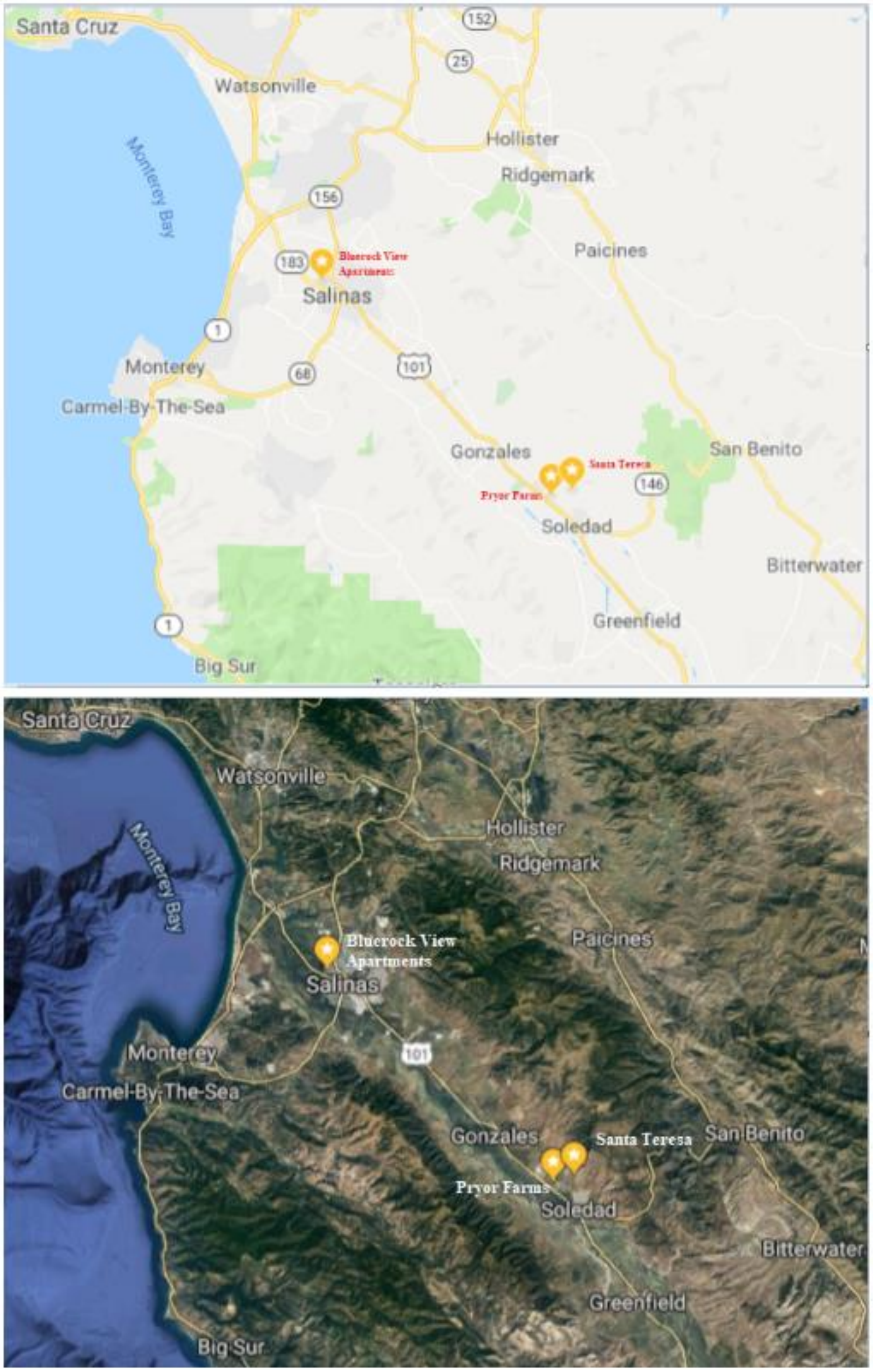

Figure E-1: *Topography and location indication of the three research sites in the Salinas Valley.*

***Figure E-1A**: Schematic illustration of the existing water system layout in Blue Rock View Apartments (Note: community sanitary wastewater is discharged to a 4,500 gallons septic tank located 112 ft Southeast of the pressure tank.).*

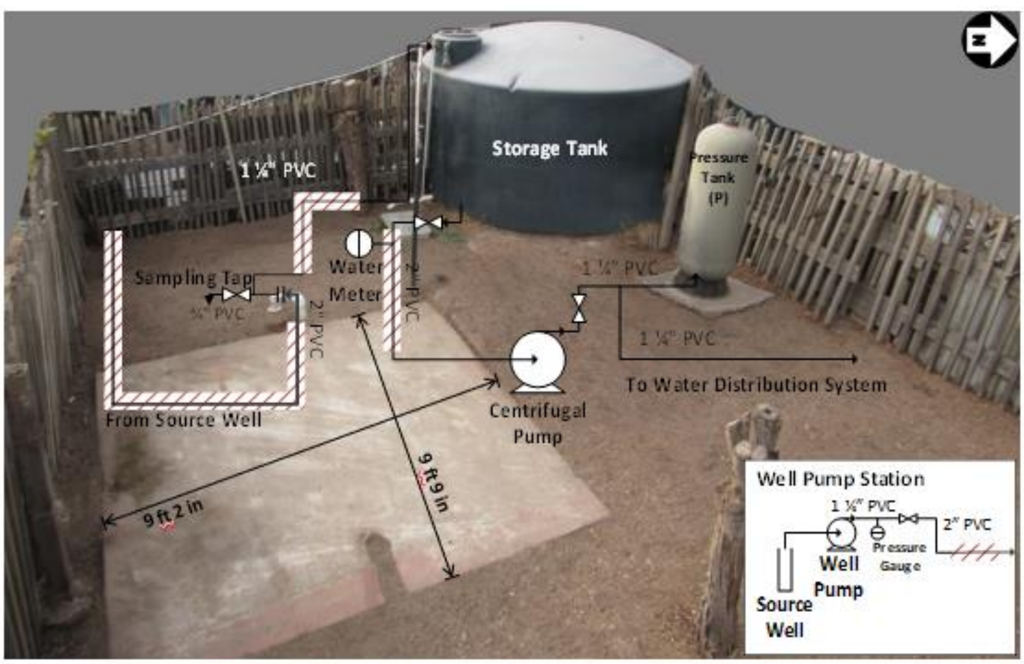

***Figure E-1B**: Schematic illustration of the existing water system layout in Santa Teresa Park Farms (Note: Community sanitary wastewater is discharged to two 2,500 gallons septic tanks located 170 ft (52 m) west and 330 ft (100 m) northwest of the pressure tank, respectively. Well pump station (inset) is located 1,250 ft (381 m) west of the pressure tank. The length of the fenced area is 21 ft long and 31 ft wide. The water distribution site has a concrete slab flooring with an area of 90 ft^2).*

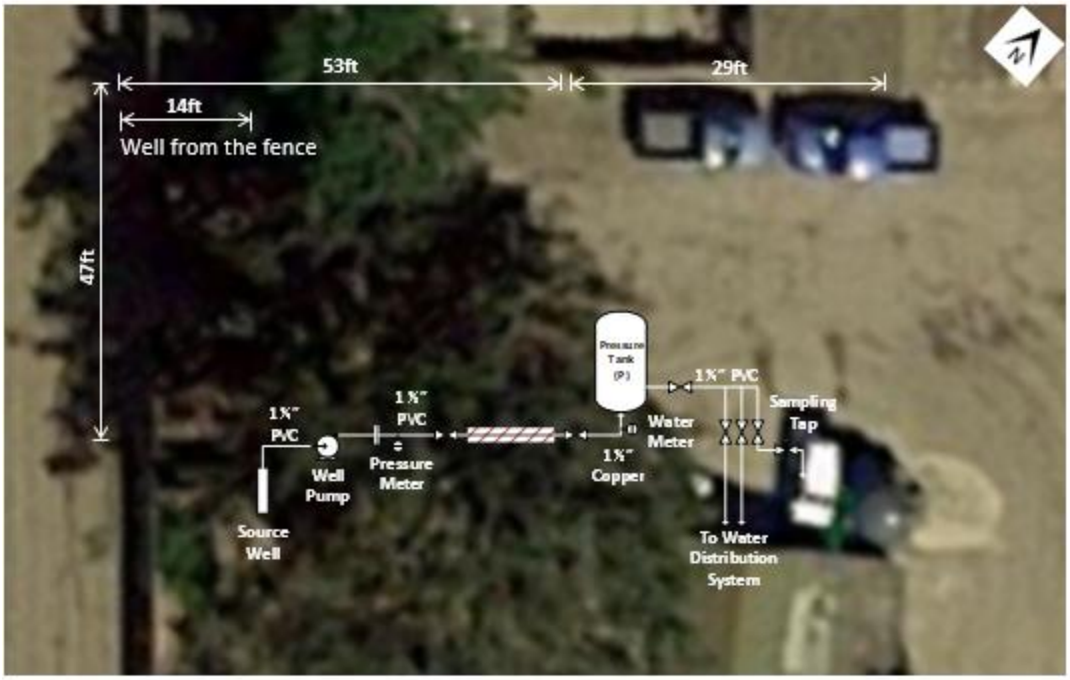

***Figure E-1C**: Schematic illustration of the existing water system layout in Pryor Farms (Note: Community sanitary wastewater is discharged to a 5,000 gallons septic tank located 220 ft (67 m) southeast of the pressure tank).*

Appendix F: System Component Information

Table F-1: List of sensors with indication of location & operating conditions.

Sensors	Location	Operating Pressure (Min-Max, PSI)	Temperature (Min-Max, F)	Average TDS (mg/L)
PI F01	Pretreatment	15-60	50-120	1300-1500
FT 01	RO Feed	60-100	50-120	1300-1500
PT 01	RO Feed	60-100	50-120	1300-1500
PT 02	RO Feed	60-100	50-120	1300-1500
CT 01	RO Feed	60-100	50-120	1300-1500
PT 03	RO Concentrate	200-300	50-150	15,000-17,000
FT 02	RO Recycle	60-100	50-150	15,000-17,000
FM-3	RO Permeate	15-30	50-150	40-100
PT 04	RO Permeate	15-30	50-150	40-100
NS 01	RO Permeate	15-30	50-150	40-100
TT 01	RO Permeate	15-30	50-150	40-100
CT 02	RO Permeate	15-30	50-150	40-100
PI D01	Post treatment	50-60	50-150	100-300
FT D01	Post treatment	50-60	50-150	100-300
FT R01	Residual Management	15-60	50-150	100-3000
HLS F01	Feed Tank	15	50-120	1300-1500
LLS F01	Feed Tank	15	50-120	1300-1500
LT D01	Potable Water Tank	15	50-120	100-300
LLS D01	Potable Water Tank	15	50-120	100-300
PS D01	Pressure Tank	50-60	50-120	100-300

Table F-2: List of pumps with indication of location & operating conditions.

Pumps	Location	Operating Pressure (Min-Max, PSI)	Temperature (Min-Max, F)	Average TDS (mg/L)
P F01	Submerged Well Pump	15-60	50-100	1300-1500
P 01	Cartridge Filter Pump	60-100	50-100	1300-1500
MP 01	AS Metering Pump	60-100	50-100	NA
P 02	RO Feed Pump	200-300	50-120	10,000-15,000
P D01	Storage/Distribution Pump	50-60	50-100	100-1500
MP 02	Chlorine Pump	50-60	50-100	NA

Table F-3: List of valves with indication of location & operating conditions.

Valves	Actuation	Location	Operating Pressure (Min-Max, PSI	Temperature (Min-Max, F)	Average TDS (mg/L)
MV F01	Manual	Maitnance/Bypass	15-30	50-100	1300-1500
MV F02	Manual	RO Feed	15-30	50-100	1300-1500
MV 01	Manual	RO Feed	15-60	50-100	1300-1500
MV 02	Manual	RO Feed	15-60	50-100	1300-1500
MV 03	Manual	RO Feed	15-60	50-100	1300-1500
MV 05	Manual	Antiscalant Dosing	15-60	50-100	NA
MV D01	Manual	Post Treatment	15-30	50-100	100-300
MV D02	Manual	Post Treatment	15-30	50-100	100-1500
MV D03	Manual	Disinfectant Dosing	15-30	50-100	NA
MV D04	Manual	Post Treatment	50-60	50-100	100-1500
MV R01	Manual	Residual Management	15-30	50-120	1500-15,000
MV R02	Manual	Residual Management	15-30	50-120	1500-15,000
AV 01	Automated	RO Feed	15-60	50-120	100-1500
AV 02	Automated	RO Concentrate	200-300	50-120	15,000-17,000
AV 03	Automated	RO Residual	15-30	50-120	15,000-17,000
AV 04	Automated	RO Permeate	15-30	50-120	40-100
CV 01	Manual	RO Permeate	15-30	50-120	40-100
AG 01	Manual	Residual Management	15-30	50-120	1500-15,000

RO Technical Manual:

Table F-4: RO membrane of choice (RE4040-BE) technical manual summary (adapted from [75]).

Membrane type description	Membrane name	RE4040-BE
	Membrane type	Thin Film Composite
	Membrane material	Polyamide(PA)
	Element configuration	Spiral-Wound
General specifications	Permeate flowrate (GPD)	2,400.0
	Nominal salt (%)	99.7
	Effective membrane area (ft2)	85.0
Operating limits	Max. operating pressure (PSI)	600.0
	Max. feed flowrate (GPD)	25920.0
	Min. concentrate flowrate (GPD)	5760.0
	Max. operating temperature (F)	113.0
	Operating pH range	2.0-11.0
	Max. turbidity (NTU)	1.0
	Max. SDI	5.0
	Max. chlorine concentration (mg/L)	<0.1
Design guidelines for various water sources	Surface water, SDI < 5 (gfd)	12.0-16.0
	Surface water, SDI < 3 (gfd)	13.0-17.0
	Well water, SDI < 3 (gfd)	13.0-17.0
	RO permeate, SDI < 1 (gfd)	21.0-30.0
Saturation limits (using antiscalants)	CaSO4 (%)	230.0
	SrSO4 (%)	800.0
	BaSO4 (%)	6000.0
	SiO2 (%)	100.0

Appendix G: Mass Balance Simulation Analysis

In the effort of establishing certainty in the simulation's (CSMPro5 with OLI studio reconciliation) result approximation, a comparison between the RO System Design simulations result and a steady-state material mass balance around the RO module were conducted. The procedure of conducting the above comparison is as follows:

1- Conduct a simulation using CSMPro5 software on multiple DACs of concern while following the previously adopted design specifications (**Tables 4-1B & 4-1C**) and note down the following parameters:

- Raw feed flowrate (Q_o, GPD)
- Module feed flowrate (Q_f, GPD)
- Permeate flowrate (Q_p, GPD)
- Concentrate flowrate (Q_c, GPD)
- Recycle flowrate (Q_R, GPD)
- Discharge flowrate (Q_D, GPD)
- Raw feed salt concentration (C_0, mg/L)
- Module feed salt concentration (C_f, mg/L)
- Permeate salt concentration (C_p, mg/L)
- Concentrate/Recycle/Discharge salt concentration (C_c, mg/L)
- Observed salt rejection (R_s, %)
- Intrinsic salt rejection (R, %)
- Single-pass recovery (%)

2- Conduct a material mass balance around the RO module (depicted in **Fig. G-1A**)

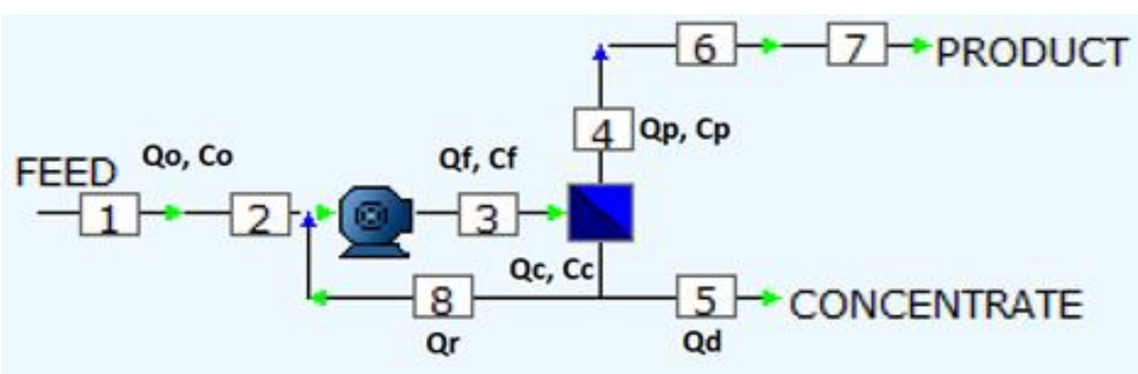

Figure G-1A: illustrative RO process schematic showing stream labels and information

3- Upon setting the overall recovery, Y, to 90%; the single-pass recovery resulting from multiple simulations within the production range per site mentioned in specifications **Table 4-1C** is averaged to produce a single-pass recovery, Y_{SP}, which is used in the mass balance calculations. The parameters Q_0, C_0, and Q_p are set according to the site-specific process specifications.

4- Upon calculating an average single-pass recovery, $\overline{Y_{SP}}$, the resulting recycle ratio, R_{ratio}, is then calculated as:

$$R_{ratio} = \frac{Y}{\overline{Y_{SP}}} - 1 \qquad \text{(G-1)}$$

5- The material balance's observed rejection value, R_s, is set equal to that of the CSMPro5 simulation ($R_s = R_{s\text{-}CSMP}$).

6- The recycle flowrate is then calculated via $Q_R = R_{ratio} * \ Q_0$ to reduce the number of unknowns in the mass balance configured around the RO recycle mix point before the feed pump:

$$Q_fC_f - Q_RC_C - Q_0C_0 = 0 \qquad \text{(G-2)}$$

And:

$$Q_0 + Q_R = Q_f \qquad \text{(G-3)}$$

7- Similarly to Eq. G-2, a steady-state mass balance around the overall RO system yields:

$$Q_fC_f - Q_CC_C - Q_pC_p = 0 \qquad \text{(G-4A)}$$

$$Q_0C_0 - Q_DC_C - Q_pC_p = 0 \qquad \text{(G-4B)}$$

8- Given the definitions for the single-pass water recovery for a single element or membrane train ($Y_{SP} = Q_p/Q_f$) and observed rejection ($R_s = 1 - C_p/C_f$), Eq. G-4A can be re-written as:

$$\frac{1}{1-R_s} - \frac{(1-\bar{Y}_{SP})C_C}{C_C} - \bar{Y}_{SP} = 0 \qquad \text{(G-5)}$$

9- Similarly, Eq. G-4B can be re-written as:

$$\frac{C_0}{C_p} - \frac{(1-Y)C_C}{C_p} - Y = 0 \qquad \text{(G-6)}$$

With overall recovery, $Y = Q_p/Q_0$.

10- Combining Eqns. G-5 & G-6 yields:

$$\frac{C_C}{C_0} = \frac{1-\bar{Y}_{SP}(1-R_S)}{1-R_S \cdot Y - \bar{Y}_{SP}(1-R_S)} \qquad \text{(G-7)}$$

Of which the concentrate salt concentration (C_C, mg/L) is found and used in Eq. G-2 to find the membrane feed salt concentration (C_f, mg/L)*.

11- Upon finding the feed salt concentration from Eq. G-2, the permeate salt concentration (C_p, mg/L) is then calculated from the simulation-produced observed salt rejection value ($R_s = 1- C_p/C_f$).

12- An identical process is done with respect to nitrate concentration to establish certainty in the simulation's result approximation in terms of nitrate removal.

Tables G-2A to **G-4A** indicate a salt removal (TDS, mg/L) comparison results between CSMPro5 (OLI studio-reconciled) simulation results and that of a steady-state mass balance calculation conducted around the RO module. Tables **G-2B** to **G-4B** indicate similar approach to the above with respect to nitrate removal (NO_3^-, mg/L as NO_3^-). The site-examples selected for this correlation are summarized in **Table G-1**.

* The feed to the membrane concentration (C_f, mg/L) is assumed to be the concentration at the membrane surface.

Table G-1: Site examples and associated key specifications defined for the comparison between simulation-originated results and results obtained from a steady-state mass balance calculation around the RO module for the sites of concern.

	DAC example site		
	Bluerock View Apartments (A)	**Bluerock View Apartments (B)**	**Santa Teresa Farms Park**
Range of permeate production (GPD)	2,400 - 3,100	2,400 - 3,100	2,700 - 4,100
Average single-pass recovery per element (%)	11.63	11.63	13.24
Number of elements in operation	3	3	3
Initial TDS concentration (mg/L)	1665.36	1593.64	561.19
Initial nitrate concentration (mg/L)	287	120	45

Table G-1A: simulation (CSMPro5) and mass balance comparison results in terms of salt concentration in the permeate for the Bluerock View Apartments (A) site example

Salt		
	Simulation (CSMPro5)	Mass Balance (Using Simulation rejection)
Q0	2666.67	2666.67
C0	1665.36	1665.36
Qf	6966.67	6874.82
Cf	11799.32	10289.96
Qp	2400.00	2400.00
Cp	114.00	99.81
Qc	4566.65	4474.82
Qr	4300.00	4208.15
Qd	266.65	266.67
Cc	17913.78	15755.29
R ratio	1.61	1.58
Rs (observed)	0.99	0.99
R	0.93	0.94
Ysp	0.34	0.35
Y	0.90	0.90
Deviation of simulation permeate concentration from calculation (%)		14.21

Table G-2B: simulation (CSMPro5) and mass balance comparison results in terms of **nitrate** concentration in the permeate for the Bluerock View Apartments (A) site example

Nitrate		
	Simulation (CSMPro5)	Mass Balance (Using Simulation rejection)
Q0	2666.67	2666.67
C0	287.00	287.00
Qf	6966.67	6874.82
Cf	2023.12	1707.57
Qp	2400.00	2400.00
Cp	34.52	29.14
Qc	4566.65	4474.82
Qr	4300.00	4208.15
Qd	266.65	266.67
Cc	3063.68	2607.78
R ratio	1.61	1.58
Rs	0.98	0.98

R	0.88	0.90
Ysp	0.34	0.35
Y	0.90	0.90
Deviation of simulation permeate concentration from calculation (%)		18.48

Table G-3A: simulation (CSMPro5) and mass balance comparison results in terms of **salt** concentration in the permeate for the Bluerock View Apartments (B) site example

Salt		
	Simulation (CSMPro5)	Mass Balance (Using Simulation rejection)
Q0	2666.67	2666.67
C0	1593.64	1593.64
Qf	6966.67	6874.82
Cf	11249.64	9892.90
Qp	2400.00	2400.00
Cp	99.10	87.15
Qc	4566.65	4474.82
Qr	4300.00	4208.15
Qd	266.65	266.67
Cc	17084.25	15152.07
R ratio	1.61	1.58
Rs	0.99	0.99
R	0.94	0.95
Ysp	0.34	0.35
Y	0.90	0.90
Deviation of simulation permeate concentration from calculation (%)		13.71

Table G-3B: simulation (CSMPro5) and mass balance comparison results in terms of **nitrate concentration in the permeate for the Bluerock View Apartments (B) site example**

Nitrate		
	Simulation (CSMPro5)	Mass Balance (Using Simulation rejection)
Q0	2666.67	2666.67
C0	120.00	120.00
Qf	6966.67	6874.82
Cf	842.31	713.98
Qp	2400.00	2400.00
Cp	14.37	12.18

Qc	4566.65	4474.82
Qr	4300.00	4208.15
Qd	266.65	266.67
Cc	1275.53	1090.37
R ratio	1.61	1.58
Rs	0.98	0.98
R	0.88	0.90
Ysp	0.34	0.35
Y	0.90	0.90
Deviation of simulation permeate concentration from calculation (%)		17.97

Table G-4A: simulation (CSMPro5) and mass balance comparison results in terms of **salt** concentration in the permeate for the Santa Teresa Farms Park site example.

Salt		
	Simulation (CSMPro5)	Mass Balance results (Using CSMPro5 rejection)
Q0	3412.22	3412.22
C0	561.19	561.19
Qf	7732.22	8250.41
Cf	3623.41	3333.87
Qp	3071.00	3071.00
Cp	38.95	35.84
Qc	4661.22	5179.41
Qr	4320.00	4838.19
Qd	341.22	341.22
Cc	5985.01	5289.36
R ratio	1.27	1.42
Rs	0.99	0.99
R	0.93	0.94
Ysp	0.40	0.37
Y	0.90	0.90
Deviation of simulation permeate concentration from calculation (%)		8.68

Table G-4B: simulation (CSMPro5) and mass balance comparison results in terms of **nitrate** concentration in the permeate for the Santa Teresa Farms Park site example.

Nitrate		
	Simulation (CSMPro5)	Mass Balance results (Using CSMPro5 rejection)
Q0	3412.22	3412.22
C0	45.00	45.00
Qf	7732.22	8250.41
Cf	284.66	255.50
Qp	3071.00	3071.00
Cp	5.70	5.12
Qc	4661.22	5179.41
Qr	4320.00	4838.19
Qd	341.22	341.22
Cc	468.45	403.96
R ratio	1.27	1.42
Rs	0.98	0.98
R	0.87	0.89
Ysp	0.40	0.37
Y	0.90	0.90
Deviation of simulation permeate concentration from calculation (%)		11.41

From the results presented above, it is summarized that the range of simulation results deviation from results originating from mass balance calculations in terms of salt concentration in the permeate (TDS, mg/L) is between 8.68 – 14.21% that increases with increasing initial concentration (C_0). In addition, nitrate concentration in permeate exhibits slightly larger deviation range of 11.41 – 18.48% that also increases with increasing initial concentration (C_{NO3-0}). It is evident that the simulation results are an approximate result originating from a set of equations based on a mass balance, and the that the results are of negligible difference with a max deviance from mass balance calculations of 18.48%.

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