Providing water for livestock and crop production to a rural area in Bonaire using reverse osmosis

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Preface and Acknowledgements

Water scarcity issues are a worldwide problem, but at each location the situation requires its own unique solution. This report investigates a possible solution for a stable water supply for the Punta Blanku region on the island of Bonaire. A stable water supply that is not overpriced will help the current agricultural business and part-time farmers and may invigorate the area and increase crop production beyond small farms towards a sustainable and economical feasible activity. Installing a reverse osmosis water treatment system will turn seawater or brackish groundwater into quality water that can be used for different agricultural purposes.

As a Master of Science student at Delft University of Technology studying Environmental Engineering, it is incredibly helpful to go abroad and learn in different environments to broaden my skills. Having never been to the Caribbean before, I not only learned of the water situation there, but also about the climate, the culture, and the people. I am grateful my school sees the importance of always pushing your boundaries to learn more. My advisors for the report, Dr.ir. S.G.J Heijman and Dr. ir. Miriam Coenders-Gerrits helped with any questions I had and provided useful information. Additionally, Dr. Heijman recommended I apply to the Lamminga Fonds, an organization that provides support for research projects in developing countries that fall under civil engineering for a donation to cover my air travel expense. I deeply appreciate that the Lamminga Fonds covered my airfare completely, a donation that made going abroad for this project possible.

This report was done in collaboration with Cooperation Punta Agua and SolteQ Energy. Without the support of either, this report would not be possible. SolteQ Energy covered the fees for a rental car and Cooperation Punta Agua provided housing and food for my two week stay, and I appreciate it a lot. Nadine Emerenciana and her family welcomed me with open arms and provided for me as one of their own. In addition to providing information about the water situation, they also taught me a lot about Bonaire and the culture, history, current topics, and people of Bonaire. I will always remember the Emerenciana family fondly and be grateful for their kindness and help.

Contents

List of Figures

List of Tables

1. Introduction

Bonaire is a small island located in the Caribbean Sea that is part of The Netherlands as a special municipality. Water scarcity is a serious issue on many smaller islands, with population growth and the predicted impacts of climate change as driving factors. Currently, the island receives drinking water from Water- en Energiebedrijf Bonaire (WEB), which produces water and distributes electricity. WEB currently produces 1600 m^3 of drinking water per day independently, and its US partner GE Water & Process Technology operates the desalination plant that produces 4000 m^3 drinking water per day, which WEB distributes. This contract ends in 2019, when WEB will take over management and operation of the desalination plant and will independently produce and distribute all drinking water on Bonaire. (Water- en Energiebedrijf Bonaire, 2018).

There are areas of Bonaire that do not have water and electricity connections to WEB. One of those areas is the Punta Blanku (Punta Blanca) region as referred to by the locals, within the Washikemba and Bara di Karta region on the eastern side of the island (Figure 1). When referring to the Punta Blanku region in the report, it implies the surrounding area of the orange location marker in Figure 1b. In the past, not having a water or electrical connection to the grid was a non-issue, as groundwater was pumped from wells and used for the farming area in the Punta Blanku region. This water was neither filtered nor underwent any treatment. It underwent natural filtration from the sediments and structures in the ground and was therefore good quality water that was safe to use for drinking water for farm animals and growing vegetables and fruits.

Due to an increase in demand and droughts over the years, the groundwater became brackish in many regions across all of Bonaire due to salt intrusion, including the Punta Blanku area. Cooperation Punta Agua is a board with members from the Punta Blanku area to find ways to produce a reliable supply of water for agricultural use in the area. This report researches a reliable and secure method using the technology reverse osmosis to provide water for agricultural purposes in the Punta Blanku region. The first phase is to produce 50 m^3 of water, and the second phase is to produce 200 m^3 water, starting one or two years after 50 m^3 water is first produced, but production need per unit of time was not specified.

Figure 1. Top figure (a) shows a map of Bonaire. The red box indicated the Washikemba and Bricat/Bara di Karta area that include the area of interest, Punta Blanku. The bottom figure (b) shows a closer view of what is contained within the red box. The balloon point shows the location of Punta Blanku farms. Source: Google Maps 2018

1.1 Punta Blanku Agriculture

Agriculture is currently a very small section of Bonaire's economy as most products are imported, but this has not always been the case as in the past Bonaire was self-sufficient and, among other things, functioned as a storage shed for Aruba and Curaçao (de Jong, 2016). Today, approximately 95% of the food for locals and tourists is imported to the island (DCNA Nature, 2018). There have been governmental plans from both Bonaire and from The Netherlands that have recommended increasing the sustainable development of agriculture and rural areas on Bonaire. The "*2014-2027 Policy Vision for Agriculture, Livestock, and Fisheries*" report details the need for expanding Bonaire's agriculture and fishery sector to boost local production (DCNA Nature, 2018). From 1966 to 1967, extensive research was done because the Central Government of the Netherlands Antilles commissioned the book "*Water and Land Resources Development Plan for the Islands of Aruba, Bonaire, and Curaçao*" which recommended expanding the local agriculture for each island using sustainable farming methods to create a diverse economy (Grontmij and Sogreah, 1968).

There are multiple reasons why the agriculture sector declined and never developed as intended up to 50 years ago, but a main factor is the dry climate and unpredictable rainy season (DCNA Nature, 2018, Grontmij and Sogreah, 1968). Bonaire has an average annual precipitation of 463 mm/year (KMNI, 2017). However, rainfall in Bonaire is extremely variable, while other climate criteria, such as mean annual temperature, humidity, wind velocity, pressure, and cloudiness remain relatively stable (Grontmij and Sogreah, 1968). For example, for the past 4 years there has been a drought with very little rain (Emerenciana N., 2018). Of the rain that falls, approximately 5% reaches the groundwater table, 10% runs off, and the rest evaporates. Only heavy rains (more than 15 mm/day) or light rains that followed a longer period of continuous rain will reach the groundwater table, while Bonaire has mostly short duration rainfalls (Grontmij and Sogreah, 1968).

Although there are many limitations, there is an active farm in the Punta Blanku region that is part of the Bonaire economy: Punta Blanku Farms N.V. Punta Blanku Farms is a family-owned business started in 1954 that provides almost all the eggs on the island. The farm used to depend on groundwater for their chicken drinking water and the water they used for their garden and goats. The other agriculture taking place in the Punta Blanku region is mostly part-time farming, where someone grows food to sell on the Saturday market. People are planting vegetables, fruit trees, and some flowers. These people also depended mostly on some local wells that pumped groundwater in the area. Over time, due to droughts and demand, the water pumped from the wells decreased in quality because they became brackish due to salt intrusion (Emerenciana N. , 2018). The use of untreated groundwater from wells was discontinued.

Punta Blanku Farms modernized their operation when they built a new chicken farm with automated equipment. Since there is no WEB connection, their energy source is a diesel generator. The generator is 2.5 years old and has a 7 to 8 year life expectancy, and costs $17,000. The cost is so high because it must be delivered to an island: a similar generator would cost approximately $5000 in the United States (Kops, 2018). They also built a concrete water tank that holds 104 m^3 water. Punta Blanku Farms uses approximately 13 to 14 m^3 water per day (Kops, 2018).

1.2 Unstable water supply

For years, groundwater pumped from wells was used on Punta Blanku Farms that was of good quality for the chickens, goats, donkeys, and vegetables. However, anyone located in the Punta Blanku cannot rely on the well water anymore. Chickens are susceptible to high levels of salt in their drinking water as it is toxic for them, causing a negative impact on the chickens' health and their egg production (Watkins *et al.*, 2005, Krista *et al.*, 1962, Selye, 1943). Brackish water is also not suitable for growing plants. For the past 2 years, the only way to have quality water is to buy it from WEB. Since there is no water or electrical connection to the grid, WEB delivers the water in trucks. This costs \$4.50/m^3 water, which is a special price for agricultural purposes and is heavily subsidised with a discount of \$13.42/m^3 (Water- en Energiebedrijf Bonaire, 2018). This water is of high quality and meets drinking water regulations. WEB also sells grey water for \$1.50/m^3 but this water is not suitable for chickens (Water- en Energiebedrijf Bonaire, 2018).

Not only is the price very expensive for water, the water supply is unreliable. The main focus of WEB is to deliver drinking water to the people in Bonaire, and understandably, providing drinking water for agricultural purposes cannot be their main concern. WEB transports approximately 10,000 m^3 water per year. WEB only has two trucks (currently one working) that can transport 6 m^3 in its tank and has multiple customers that rely on water. If the truck breaks down, WEB does not deliver water and provides neither insurance nor reimbursement for any consequences that happen to the customers without water (Emerenciana N. , 2018). In the past, this was a larger issue. Punta Blanku Farms would order trucks to come every day but some days they were unable to come. Water would not be delivered and the chickens would be without water some days. In September 2017, Punta Blanku Farms had to buy 80 m^3 water from a private party and the costs were astronomically high and far outside of their budget. Eventually, Punta Blanku Farms made the situation public with a TV interview in October 2017 about how they were not getting reliable water from WEB (Emerenciana N., 2018).

While discussing with WEB about compromises and solutions for the issue on reliability, WEB was unable to provide a viable solution that was cost effective for them and cost effective for Punta Blanku Farms. One of their solutions was that Punta Blanku Farms would purchase a water truck, but after calculations made by Punta Blanku Farms, it was not possible to do this due to cost. In addition to paying for the truck, they would still have to pay for water and other costs like maintenance, fuel, and a driver (Emerenciana N. , 2018). Since the TV interview, WEB prioritises bringing water to Punta Blanku Farms, but if something outside of their control occurs that hinders access to Punta Blanku, such as both of their trucks breaking down for a longer period of time or if the roads leading to the farm become undriveable, they would not be able to provide water even if they wanted to due to circumstances outside of their control.

One of the part-time farmers in the Punta Blanku region, Onnie Emerenciana, relied on a public well near his farm for growing vegetables and fruit trees. Ideally, Onnie would like to focus all of his time on farming as a career and improving the surrounding area to attract tourism, but that is not possible without continuous access to water. At first, he relied on WEB to bring 6 m^3 water once per week. Initially, WEB was able to deliver and keep up with demand, but then without warning, they were unable to deliver water. They were also not able to provide a timeline of when they would be able to deliver water due to high demand. Justifiably, WEB cannot prioritise providing water for plants over water for humans and livestock, but this does impact crop and produce farmers. Now, Onnie uses a public well near his house but sometimes it provides brackish water. He has lost plants because of this and it hinders his ability to expand. Over the years, less people are interested in growing plants in the area because they are incapable to do so without access to a reliable water source. (Emerenciana O., 2018).

1.2.1 Climate Change

Although currently the unreliable water supply is due to WEB being the only provider and not being able to meet demands, climate change may cause further impacts in the future if ground water is used as a source, even if the groundwater is brackish and treated. A study was done to analyze future climate when the mean global surface air temperatures are 1.5°C, 2.0°C, and 2.5°C over preindustrial values (Taylor, et al., 2018). For the Caribbean, at a 1.5°C temperature increase, expectations are that Bonaire will become drier and have an increase in annual warm spells of more than 100 days. At a 2.0°C temperature increase, models show additional warming by 0.2°C – 1.0°C, a further extension of warm spells by 70 days, a shift to becoming a drier region, and more droughts. At a 2.5°C temperature increase, the expectations are the same as of a 2.0℃ temperature increase but more intense (Taylor, et al., 2018). Even if global changes are made today to lower carbon emissions and live more sustainably, Bonaire will very likely experience a drier climate in the future and it is best to prepare for that.

1.3 Reverse Osmosis

Reverse osmosis (RO) is a water treatment technology that uses high pressures to feed water through a semipermeable membrane that rejects monovalent ions and particles that are larger than monovalent ions. From one incoming stream, RO will produce two outlet streams: the permeate and the concentrate, or brine. The permeate is the product water without the contaminants. The brine is the concentrate stream that contains the contaminants. RO membranes are often used for desalination to remove Na^+ and Cl^- from water. RO membrane technology is developed for both brackish and seawater applications. Brackish water RO (BWRO) membranes will typically have higher permeate flux, lower salt rejection, and require lower operating pressures due to the lower osmotic pressures of less saline waters, while seawater RO membranes (SWRO) require maximum salt rejection and therefore necessitate higher operating pressures. SWRO membranes have greater than 99% salt rejection (Brehant *et al.,* 2003, Reverter *et al.*, 2001). Membranes designed for higher salt rejection will have lower permeate fluxes due to the trade-off between membrane selectivity and membrane permeability. SWRO membranes operate at higher pressures to compensate for the higher osmotic pressure of seawater. (Greenlee *et al.*, 2009)

Due to Bonaire’s size and available water sources (either seawater or brackish groundwater), reverse osmosis will be the main technology used for water treatment in the Punta Blanku region. WEB uses reverse osmosis to produce their drinking water, and reverse osmosis is used world wide for desalination (Water- en Energiebedrijf Bonaire, 2018, Greenlee, *et al.*, 2009). The location of the water tank at Punta Blanku Farms could be a good location to place the reverse osmosis system. The water tank is made of concrete and is big enough to hold an approximate week's worth of water supply for the farm.

1.3.1 Principles of Osmosis

Osmosis must be understood first before explaining reverse osmosis. When two containers of water with different concentrations of ions are connected via a semipermeable membrane, water with the low concentration of ions will cross through the semipermeable membrane to the container with high ion concentration water (Figure 2). The ions are rejected and cannot pass the semipermeable membrane. This increases the volume and decreases the concentration in one container while decreasing the volume and increasing the concentration in the other until an equilibrium between the concentrations is formed. This process is called osmosis. The driving force behind this process is called osmotic pressure as an increase in the concentration of ions results in an increase of osmotic pressure. The minimum pressure applied to the solution to prevent inward flow of the lower ion concentration water across a semipermeable membrane is equal to the osmotic pressure (Voet *et al.*, 2001).

1.3.2 Principles of Reverse Osmosis

In reverse osmosis the flow of water is reversed. The water flows from high concentration to low concentration, resulting in a permeate flow with low concentration of ions and other contaminants as the semipermeable membrane rejects the ions and larger particles. The brine is then very concentrated with the ions and contaminants. A RO membrane is operated by achieving a hydrostatic pressure greater than the osmotic pressure of the solution (Figure 2). This pressure is called the trans membrane pressure. Overcoming the osmotic pressure allows the water to flow from high concentration to low concentration. The positive difference in pressure creates a concentration gradient across the membrane that drives the liquid through the membrane against the natural direction of osmosis while the ions are retained and concentrated on the surface of the membrane. A few ions passing through the semipermeable membrane is possible (Greenlee *et al.*, 2009).

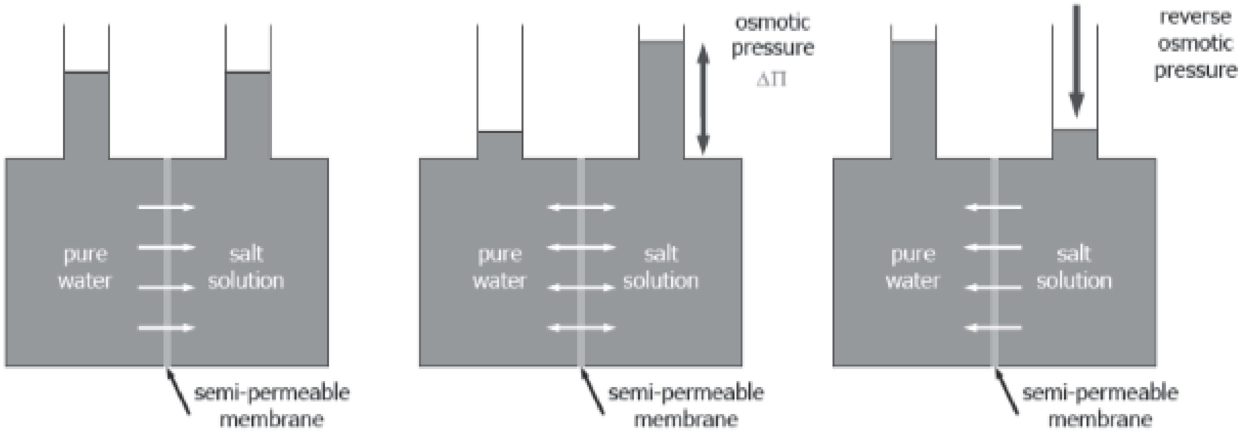

Figure 2. Schematic of osmosis (left and middle beaker) and reverse osmosis (right beaker). (van Lier, 2011).

1.3.3 Recovery

The recovery is the fraction of influent water that becomes the permeate. A higher recovery indicates more permeate. A higher recovery is often achieved at the cost of having lower ion rejection, which reduces the quality and purity of the permeate. Additionally, an increase in recovery also means in increase in energy usage. Typically, multiple membranes are placed after each other so the concentrate passes multiple membranes to increase the overall recovery. For desalination, a high salinity is considered a value above 55,000 mg/L TDS and a high recovery is considered above 35% (Greenlee *et al.*, 2009). Lower total dissolved solids allow for higher recoveries due to a lowered need for applied pressure. Recovery for brackish water reverse osmosis (BRWO) can range from 70–97% while recovery for sea water reverse osmosis (SWRO) ranges from 35–45% (Lenntech, 2023).

1.3.4 Fouling

RO performance is negatively impacted by concentration polarization and fouling, such as scaling or biofouling. The rejection of ions and larger particles by the membrane results in an accumulation of them in the concentrate. The highest concentrations occur directly at the membrane, called concentration polarization. The increase in concentration results in an increase in osmotic pressure, which further increases the pressure needed and the leakage of ions through the membrane (Macedonio & Drioli, 2010)

Scaling is a form of fouling. Either during concentration polarization or from an increase in concentration of ions to achieve high recovery, the solubility of the ions can be exceeded resulting in precipitation. Calcium (Ca^{2+}), magnesium (Mg^{2+}), and carbonate (CO_3^{2-}) are the ions most likely to cause scaling. Lowering the pH or adding anti-scaling agents can reduce the effects of scaling (Macedonio & Drioli, 2010). Another form of fouling is biological fouling. Microorganisms present in the inlet water can, under favourable conditions, form a biofilm on the membrane through reproducing, called biofouling. The concentration of nutrients available in the inlet water is increased as permeate is produced, creating an ideal environment for the microorganisms. Biofouling leads to a reduction in the permeability of the membrane, which is overcome by increasing the feed pressure, leading to higher energy usage (Bar-Zeev & Elimelech, 2014). Biodegradation is also possible, where acidic by-products of the microorganisms damage the membrane (Macedonio & Drioli, 2010).

Physical fouling is caused by suspended solids, colloids, and microorganism matter on the membrane. Membrane (microfiltration (MF) and/or nanofiltration (NF)) pre-treatment usually removes these, and colloidal particles sometimes require coagulation or flocculation (Macedonio & Drioli, 2010). To prevent fouling, the particles should either be removed beforehand or recovery can be lowered. Additionally, it is possible to clean the membranes more often to prevent build-up, often through backwashing with permeate or clean in place procedures.

1.4 FreshWaterMill from SolteQ Energy

As RO requires a high amount of energy, picking a sustainable way to fuel it is ideal. A RO system could be powered by a diesel generator, or eco-friendlier through wind energy or solar panels. SolteQ Energy has developed the FreshWaterMill, a hydraulic wind mill that uses a hydraulic transmission to transfer high pressure energy to a RO system and an optional electrical generator. The use of a hydraulic transmission to deliver power, rather than a more typical electromechanical transmission, reduces conversion losses, since losses in the gearbox, generator and electric motor driving the high-pressure pump are eliminated (Solteq Energy, 2018). The electrical generator can also be used to provide electricity to other functions if there is excess energy, not just to operate and maintain the RO system.

The FreshWaterMill has multiple advantages, including sustainability, low service and maintenance needs, hurricane/storm safe, long life expectancy, low operational costs, resistant against sand and dust, and resistant against salt (Solteq Energy, 2018). Due to Bonaire's windy conditions, this could be an optimal, environmentally friendly installation in the Punta Blanku region. Although the purpose of this paper is not to determine whether to use a FreshWaterMill with reverse osmosis system, it is an option available for Cooperation Punta Agua.

1.5 Research Objective

This study focuses on answering some of the logistical questions of a reverse osmosis installation for water treatment in the Punta Blanku region for agricultural reasons, specifically chickens, goats, and vegetables. It is important that if investments are made to produce water, the water is of good quality and the water treatment technology is working in optimal conditions. This report aims to answer the following research questions:

1. What should be the source of inlet water: sea water or brackish groundwater?
2. What is the quality of inlet water? Are pretreatment steps necessary; if yes, which steps?
3. What is the quality of the permeate? Are post treatment steps necessary; if yes, which steps?
4. How to dispose of the brine: dispose into the ocean or onto salt pans?
5. Are there possibilities of energy production or decreasing energy usage?

2. Materials and Methods

Samples were taken at four different locations (Figure 3) that could be possible sources of water by BONLAB Bonaire Laboratorium N.V. The locations of the samples were from wells that are in existence. Results of the samples and consideration of other environmental and logistical factors were compared to determine the best possible source water. The factors include amount and availability of source water and whether Cooperation Punta Agua wants to produce salt from the brine. Samples were measured for the following parameters:

- Temperature
- pH
- Conductivity
- TDS
- Iron
- Nitrite
- Aluminum
- Phosphorus
- Total Nitrogen
- COD

Information to answer the questions were gathered from talking to the board of Cooperation Punta Agua, employees and managers of Punta Blanku Farms, hobby farmers, and collecting information from sources provided by SolteQ Energy, Cooperation Punta Agua, and literature research.

IMSDesign, a model made by Hydranautics (Nitto Group Company), was used to model SWRO and BRWO to compare total pumping power needs.

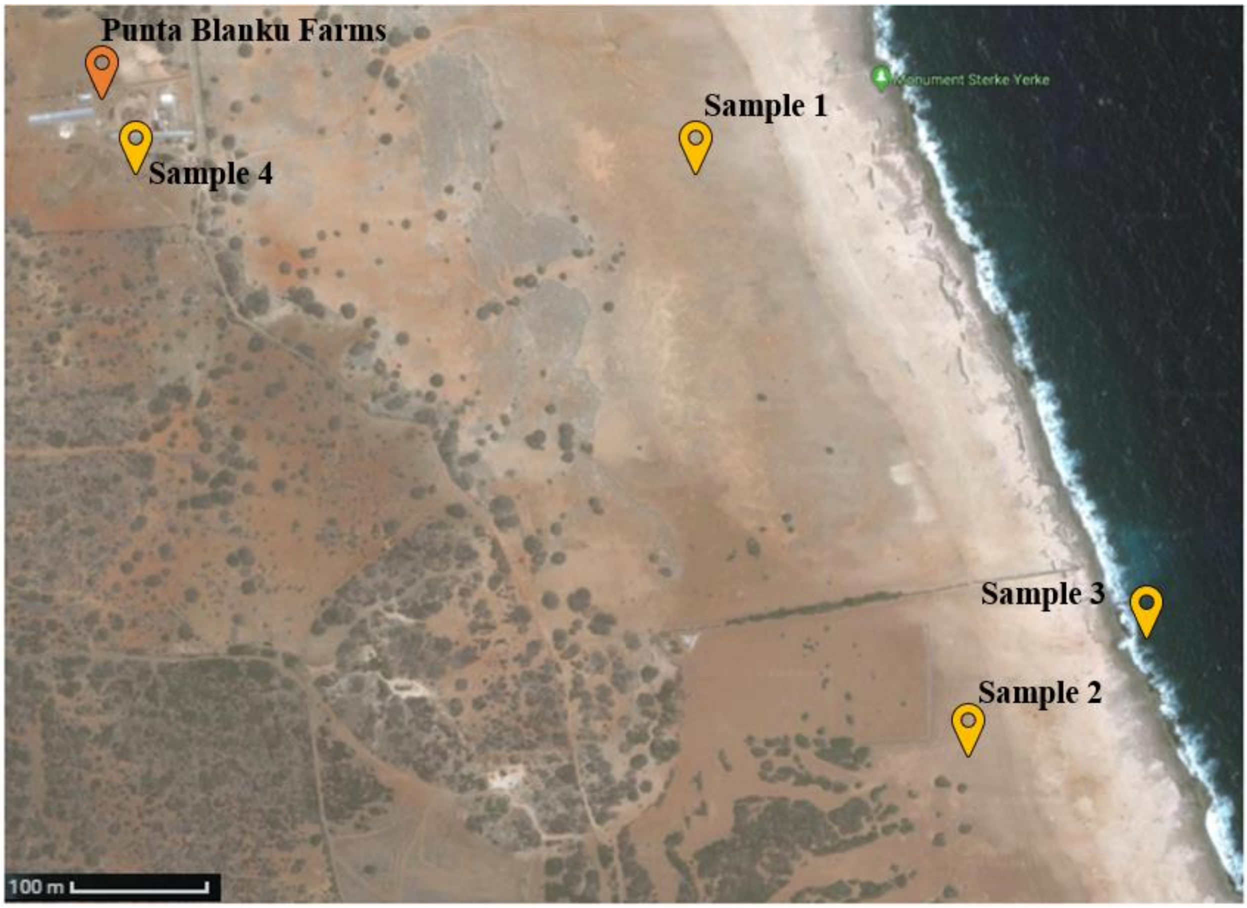

Figure 3. This map shows the locations of where the four samples were taken as well as the location of Punta Blanku Farms. Samples 1 and 2 are water samples from uncovered wells, sample 3 is from seawater, and sample 4 is from a covered well.

3. Results

3.1 Laboratory Results

BONLAB Bonaire Laboratorium N.V. tested sample from four different water source locations. The results are shown below in Table 1. BONLAB performed a full chemical analysis that the laboratory was capable of. BONLAB was unable to perform Saturation Index, hardness, Ca^{2+}, HCO_3^-, boron concentration, and turbidity tests. Sample 1 and 2 were both from uncovered wells, meaning that the water was a mix of rain water and groundwater. Sample 3 was from seawater and sample 4 was from the well that used to provide drinking water for the chickens and water for the garden but has been discontinued for use for chickens for two years and for vegetables for approximately 3 to 4 months after the farmers realized it had a higher salt content. The well was pumping for approximately 24 hours before a sample was taken but had not been in use or pumping for the previous 3 to 4 months.

Table 1. Measurements of selected parameters for the samples from different water sources

Sample ID	**1**	**2**	**3**	**4**
Date	21 Nov 2018	21 Nov 2018	21 Nov 2018	22 Nov 2018
Temperature (°C)	29.0	27.5	28.0	31.0
pH	7.66	8.04	8.19	7.12
E. Conductivity (µS/cm)	8370	1346	54,300	2970
TDS*	4.19	673	27	1.5
Iron (µg/L)	0.03	0.03	0.01	0.72
Nitrite (mg/L)	0.061	0.057	0.044	0.066
Aluminum (µg/L)	<0.02	<0.02	<0.02	<0.02
Phosphorus**	<1.5	<1.5	<1.5	<1.5
Total nitrogen***	8.95	15.8	3.73	34.8
COD****	32.1	4.18	1202	12.5

Sample 1 location: uncovered well water approximately 100m from the coast.
Sample 2 location: uncovered well water at Roi Lamunchi, approximately 100m from the coast
Sample 3 location: Sea water
Sample 4 location: Covered well water, approximately 100m from chicken farm

*TDS units not provided by BONLAB Bonaire Laboratorium N.V.
**Phosphorus units not provided by BONLAB Bonaire Laboratorium N.V.,
***Total nitrogen units not provided by BONLAB Bonaire Laboratorium N.V.
****Total COD units not provided by BONLAB Bonaire Laboratorium N.V.

Total dissolved solids (TDS) and electrical conductivity are parameters used to characterize the water specifically for RO. Freshwater usually has an electrical conductivity of 0 – 1,500 µS/cm and seawater usually has an electrical conductivity of approximately 50,000 µS/cm (Water quality standards, 2013). Samples 1, 2, and 4 all fall in the range of brackish groundwater, and the sample from the sea has an electrical conductivity that matches approximately what is expected for seawater. Fresh water is characterized by having less than 1000 mg/L of salts or TDS. Most seawater sources contain 30,000 – 45,000 mg/L TDS and brackish groundwater sources contain 1000 – 10,000 mg/L TDS (Greenlee *et al.*, 2009). BONLAB did not provide units for TDS, and even if we assume the most common units for them (ppm or mg/L), the TDS values do not seem correct when comparing them to electrical conductivity, as there is commonly a linear relationship. Therfore we calculate TDS values based on the electrical conductivity values using Lenntech's conductivity convertor which assumes total dissolved solids (in ppm) is equal to the electrical conductivity (in µS/cm) multiplied by 0.640 (Table 2).

Table 2. Measurements of selected parameters for the samples from different water sources

Sample ID	**1**	**2**	**3**	**4**
E. Conductivity (µS/cm)	8370	1346	54,300	2970
Calculated TDS (ppm)	5357	861	34,752	1901
BONLAB TDS*	4.19	673	27	1.5

*TDS units not provided by BONLAB Bonaire Laboratorium N.V.

Seawater typically contains between 1 – 3 µg/L of iron and groundwater contains 100 mg/L, drinking water cannot contain more than 200 µg/L (Lenntech, 2018). All of the samples meet the regulations and are below the limit for health impact from iron. The amount of aluminum in seawater ranges between 0.013 – 5 µg/L, and current standards for aluminum in drinking water is between 50 – 200 µg/L (Lenntech, 2018). All of the samples are below the recommended Aluminum levels and do not pose a concern. Adult chickens are monogastric animals and therefore quickly discard of nitrite and nitrate in their urine, but young chicks are susceptible to nitrate poisoning until their digestive systems develop (Lenntech, 2018). In the United States, the Environmental Protection Agency set the maximum level for nitrite at 1.0 mg-N/L (Water Quality Association, 2013). With the conversion, all the samples have a nitrite concentration more than five times below the EPA standard.

The temperature listed appears to be high. Samples were brought to the lab in a cooler, but it is not known the procedure of BONLAB once samples were delivered. Ideally, some parameters, such as temperature, electrical conductivity, and pH, would be measured with a field instrument immediately after samples are collected.

3.2 Reverse Osmosis Model Results

Using IMSDesign, a model made by Hydranautics (Nitto Group Company), a reverse osmosis system can be modelled virtually to determine power requirements and feasibility of installing a wind turbine. Using a diesel generator would not be financially prudent for Cooperation Punta Agua. The two most particle water sources were modeled: sample 3 (seawater) and sample 4 (brackish groundwater). At high salinities and high permeate recovery, higher pressures and membranes designed for high pressure are required, increasing initial and operational costs (Greenlee, Lawler, Freeman, Marrot, & Moulin, 2009). Design was tested for permeate production at 50 m^3/day and 200 m^3/day. These values are much higher than the current need, but RO systems can be scaled down at a later stage if needed. SWRO will have one raw, feed, concentrate and permeate streams (Figure 4a). Feed water is raw water post pump. Due to the lower electrical conductivity and total dissolved solids for brackish water, BRWO can be designed with two stages where the concentrate from the first stage goes through RO again to increase recovery and decrease the amount of raw water needed (Figure 4b). The most important design parameters are provided in Table 3, and extra design parameters are provided in the appendix. Systems were designed to be within the limits set by IMSDesign.

BWRO requires far less power and raw water than SWRO. Although design was not perfectly optimized due to limited data, future power needs will follow the same trend due to TDS values. Investment costs were largely dependent on permeate production and can be lowered with optimization.

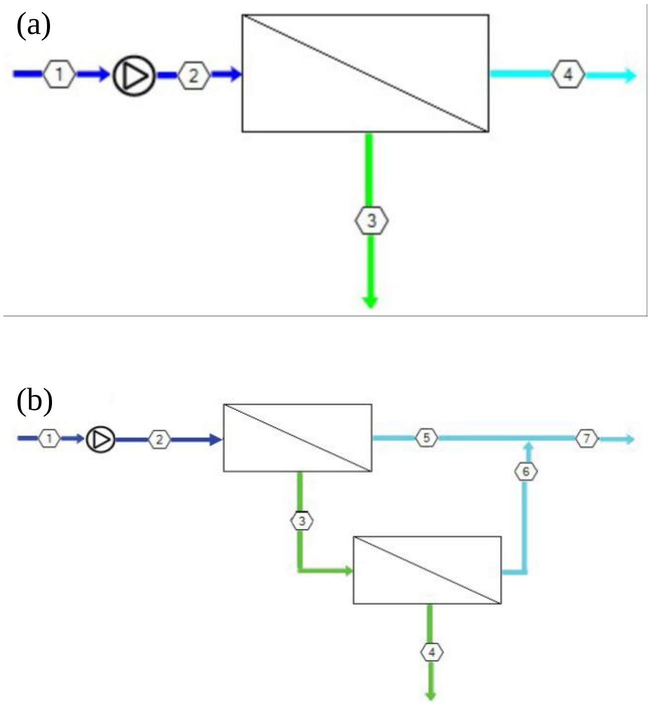

Figure 4. (a) Flow diagram for SRWO and (b) BRWO with two stages for first stream concentrate recovery. Dark blue arrows indicate raw and feed water, green arrows indicate concentrate, and light blue arrows indicate permeate.

Table 3. Important design parameters for modeled reverse osmosis systems with sea water (sample 3) and brackish water (sample 4) as feed water

Sample ID	3 - SWRO	4 - BWRO	3 - SRWO	4 - BRWO
Water Type	Sea Surface Conventional	Brackish Well Non-Fouling	Sea Surface Conventional	Brackish Well Non-Fouling
Permeate Production (m^3/day)	50	50	200	200
Permeate Recovery (%)	40	70	40	70
Feed Flow (m^3/day)	125	71.4	500	285.7
Concentrate Production (m^3/day)	75	21.4	300	85.7
RO System	SWC4 MAX	ESPA2-LD-4040	SWC4 MAX	ESPA4-LD-4040
Elements/Vessel	4	Stage 1,2: 7,4	5	Stage 1,2: 5,5
Vessels	1	Stage 1,2: 1, 1	3	Stage 1,2: 6,3
Total elements	4	11	15	45
Measured E. Conductivity (µS/cm)	54,300	2970	54,300	2970
Model E. Conductivity (µS/cm)	55,409	2979	55,409	2979
Permeate E. Conductivity (µS/cm)	421	77.8	391	274
Concentrate E. Conductivity (µS/cm)	87998	8743	88011	8401
Permeate TDS (mg/L)	421	77.8	391	126
Total pumping power (kW)	9.7	0.9	39.6	2.3
Pumping specific energy (kWh/m^3)	4.68	0.41	4.75	0.28
Investment Cost (€)	46,145.00	46,144.91	184,580.00	184,579.60

3.3 Wind Speed and Windmill Power

Average wind speed in Bonaire is 7–8 m/s and the windy season is from the beginning of December to the beginning of August (Figure 5). Although wind speed will vary throughout the day and over months, for 9 months of the year wind speed reached above 5.5 m/s over 90% of the days over the course of each individual month, and above 5.5 m/s approximately 70% of the days over the course of each individual month for October, November, and December (Figure 6).

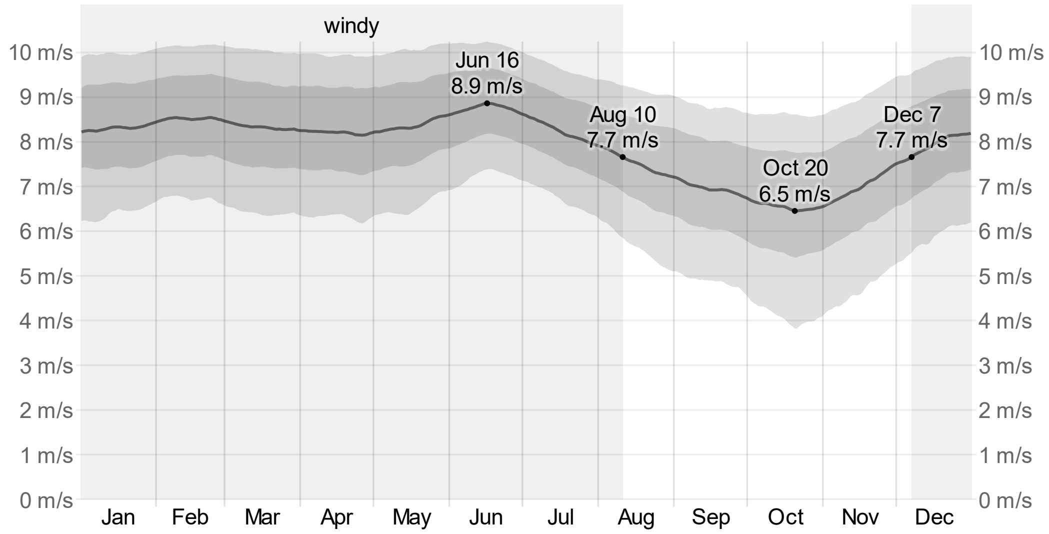

Figure 5. Average of mean hourly wind speeds in Bonaire from 2015-2023 at 10m above ground level with 25th – 75th and 10th – 90th percentile bands (WeatherSpark, 2023)

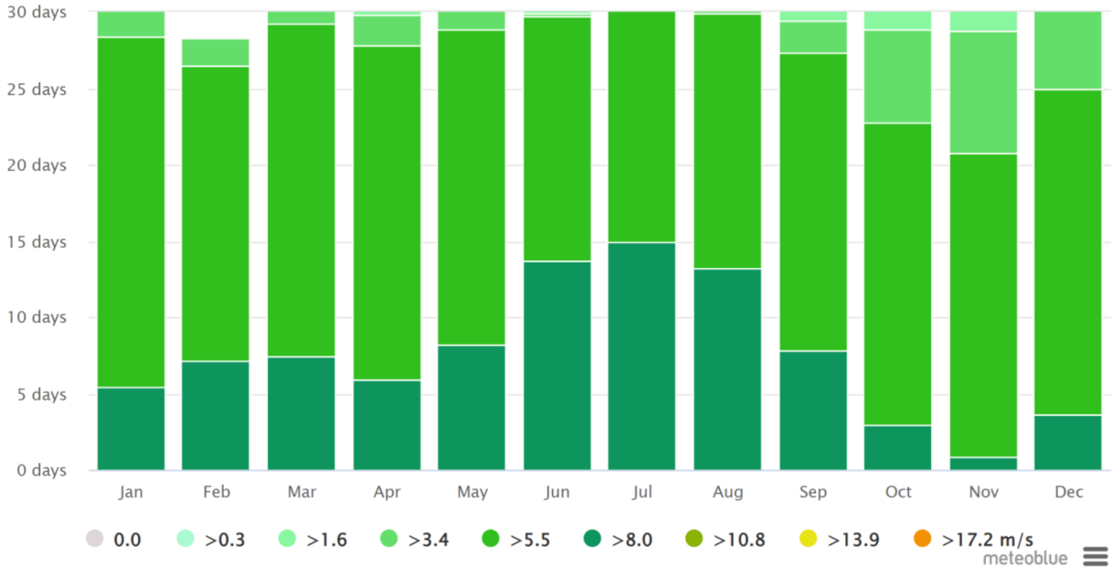

Figure 6. 30 year averaged data of the amount of days per month wind speed reached above specified amount (Meteoblue, 2023)

Among other design parameters, windmills provide electrical power based on wind speed. The performance graph of FreshWaterMill provides the relationship between wind speed and power (Solteq Energy, 2018). At a wind speed of 5.5 and 7 m/s the electrical power is approximately 8 and 19 kW, respectively (Figure 7). Based on the total pumping power for BRWO and SRWO (Table 3), at a wind speed of 5.5 m/s, only BRWO (both 50 and 200 m^3/day permeate production) could be powered by FreshWaterMill. At a wind speed of 7 m/s, BRWO (both 50 and 200 m^3/day permeate production) and SWRO for 50 m^3/day permeate production could be powered by FreshWaterMill.

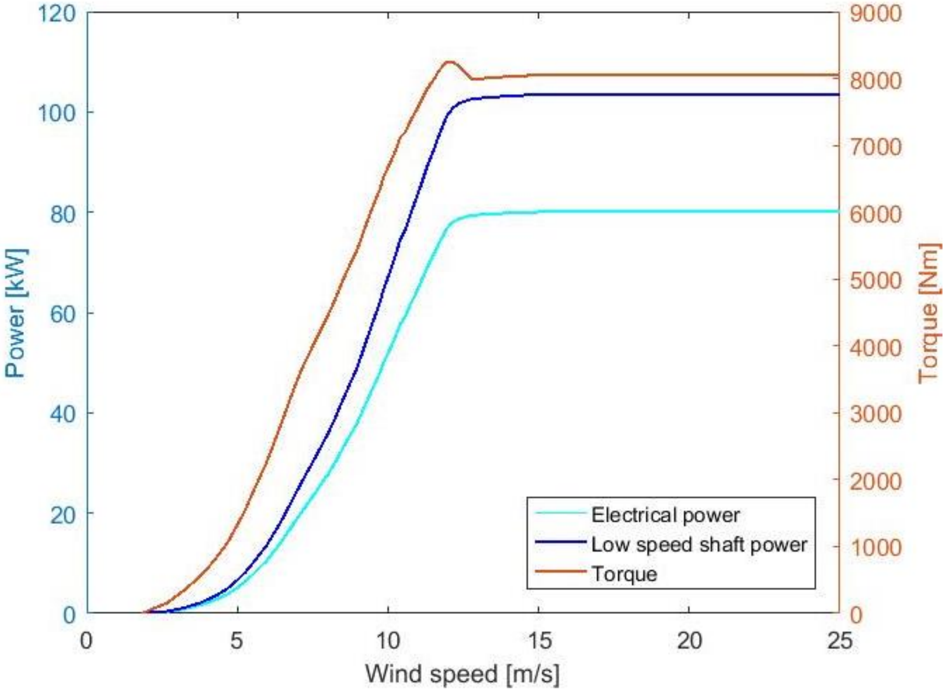

Figure 7. FreshWaterMill performance graph for wind speed and electrical power (image provided from Bas Heijman through email communication)

4. Discussion

4.1 Source Water

Advantages of using brackish groundwater with reverse osmosis treatment (BWRO) over using seawater with reverse osmosis treatment (SWRO) are a lower membrane fouling hazard specifically from biomass, suspended particles, and SO_4 precipitates), lower energy demand, less need for extensive post-treatment (especially regarding boron removal), and lower costs (Stuyfzand & Raat, 2010). The disadvantages of using BWRO instead of SWRO usually include higher concentrations of ions like Fe, Mn, SiO_2, NH_4, PO_4, and HCO_3 in brackish groundwater and these ions increase the risk of membrane fouling, quality of groundwater is often not constant, and more issues with disposal of the concentrate due to a higher nutrient concentration (Stuyfzand & Raat, 2010). Energy demand and operation costs related to energy demand will not be an advantage of BRWO if FreshWaterMill or another sustainable option is chosen to power the treatment system. If a diesel generator is used to power the RO system instead of wind energy or solar panels, then the cost of operation would be higher for SWRO than BWRO.

Additional advantages of SWRO are that there is a virtually unlimited supply of water and if Cooperation Punta Agua would like to dispose of the concentrate by producing salt with salt pans, the sea water will provide more salt than brackish water would. If there is 30% recovery for the RO installation and it produces 50 m^3 permeate per day or 200 m^3 permeate per day, 167

m^3/day or 667 m^3/day would need to be pumped, respectively. Recovery could be higher or lower depending on the inlet water. Recommendations in the past included pumping no more than 86.4 to 172.8 m^3/day per hectare (100m^3) based on low permeability of aquifers and the quantity of water available (Grontmij and Sogreah, 1968). This limit is not completely applicable as Cooperation Punta Agua would not pump freshwater, but pumping more brackish water could lead to even more saltwater intrusion.

Although results and RO model design provided in this report are preliminary, based on these initial results, installing BWRO is recommended. Pretreatment and post treatment is likely unnecessary based on previous water usage and natural filtration from the soil, and power demand will be significantly lower than SWRO. Taking into account that at times the wind speed will be below the average and extremely high diesel costs (financially and environmentally), it is best if the power requirement of the RO system is as low as possible.

4.2 Pretreatment for Reverse Osmosis

Pretreatment for a reverse osmosis system is done to prevent membrane fouling and prevent flux decline. Membrane fouling leads to a decline in the performance of the RO system. Common parameters used to determine performance levels for RO are turbidity and Silt Density Index (SDI). The general maximum limits for turbidity are 1 NTU and a SDI of 3 to 5 depending on the type of membrane (Lenntech, 2001). BONLAB was not able to measure turbidity, a critical parameter. Saturation index is also a valuable parameter to use as a risk index to estimate precipitation and thus scaling. When SI is less than 0 precipitation is not expected to occur and when SI is greater than 0 to 0.2, precipitation and clogging on the membrane may occur (Stuyfzand & Raat, 2010).

For SRWO, since seawater will have a higher tendency for membrane fouling it requires more extensive pretreatment than surface water or groundwater (Greenlee *et al.*, 2009). In this situation, the brackish water has been filtered naturally through soil, and it likely that pretreatment is not required. Without the full chemical analysis, it is difficult to determine the pretreatment for either SRWO and BRWO. Coagulation is typically seen as the conventional pretreatment to remove small particles for SRWO, but it not feasible to install this type of treatment for a small operation that is not a large desalination plant (Valavala *et al.*, 2011). Using ultrafiltration (UF) and/or microfiltration (MF) is another pretreatment method that is becoming popular. Although UF/MF could have a higher capital costs of up to 25%, life cycle costs are comparable, and UF/MF requires less chemicals, RO can operate at a higher flux, lower RO operating costs as membrane cleaning frequency is lowered (Valavala *et al.*, 2011). It is possible that filtration is not a necessary step for pretreatment depending on the turbidity of both SRWO and BRWO and because of the small scale of the RO operation.

For SRWO, biological fouling can be a more pressing issue than for BRWO. Chlorination is often used to prevent biological fouling. Chlorine and organic chemicals can lead to damage on the membranes and are ideally removed before reaching the RO system, which can be accomplished through dosing of bisulfate (Lenntech, 2018). As seen in table 1, the pH of the seawater is 8.19. Dosing with acid to lower the pH to prevent scaling may be necessary in this case due to the pH and depending on the SI. Instead of dosing with acid, dosing with antiscalants to prevent formation of all scales is often done as usually less antiscalant is needed than, for example, sulfuric acid (Lenntech, 2018). Due to the filtration of the soil, the brackish ground water would likely need less pretreatment steps, but this depends on the turbidity and SI.

Due to the small-scale operation and the possibility to store water, it could be more effective to keep the operation simple and not add a pretreatment technology step, only dosing. It is likely that the membranes would have to cleaned more often, but this could be done by Cooperation Punta Agua and it would not hinder the overall production goal. BWRO may require NaOH dosing to lower the pH and reduce fouling.

4.3 Post Treatment

Post treatment mostly depends on the quality requirements of what the permeate is used for, and how the brine is being disposed, as well as complying with regulations and guidelines. Cooperation Punta Agua will not be allowed to produce drinking water for human consumption due to government regulations (van Tonningen, 2018). Hypochlorite is often used for post treatment in drinking water for human consumption to inactivate pathogens and provide residual disinfection in the distribution systems, however, it is also often used for the same reasons for poultry drinking water (Smith, 2011, Scott *et al.*, 2009). If using BRWO, a post treatment disinfectant is likely not necessary as in the past this water was used with no issues for either chickens or plants and was only discontinued for its salt content. If using SRWO with pretreatment to hinder biofouling, hypochlorite is probably also not necessary since there should be low risk of pathogens that are usually present in surface water, especially since distribution will be to a very small region in Punta Blanku. Additional disinfection is not required for irrigation if the water is not sprayed on the leaves of the plants.

Table 2 below shows some general guidelines for poultry drinking water. Boron is very hard to remove using RO and can be found in high concentrations in sea water and brackish groundwater (Stuyfzand & Raat, 2010). Just like turbidity and SI, additional tests must be taken for boron concentration. Chickens benefit from boron levels of no higher than 200 mg/L (Jin *et al.*, 2014) and plants require boron but it can be toxic if irrigated with water containing high levels of boron (Camacho-Cristobal *et al.*, 2008). If there are high concentrations of boron in the inlet water, specific high boron removal RO membrane elements or boron ion exchangers need to be installed (Taniguchia *et al.*, 2004, Glueckstern & Priel, 2007). A boron test will have to be taken.

If BRWO is used, as recommended, it is likely that no post treatment is necessary as this water was not treated before salt intrusion and the use was discontinued due to the salt content.

Table 4. Drinking water quality guidelines for poultry (Fairchild & Ritz, 2015)

Characteristic	Maximum Accetable Levels
Bacteria	
Total Heterotrophic Bacteria	100 CFU/100 mL
Coliform Bacteria	50 CFU/100 mL
pH	5.0 - 6.8
Hardness	110 ppm
Naturally Occurring Compounds	
Calcium	500 ppm
Chloride	250 ppm
Copper	0.6 ppm
Iron*	0.3 ppm
Magnesium	125 ppm
Manganese**	0.05 ppm
Nitrate	25 ppm
Phosphorus	0.1 ppm
Potassium	500 ppm
Sodium	50 ppm
Sulfate	250 ppm

*Iron concentration as high as 600 ppm has shown to have no effect on bird health, but can have detrimental impacts on water lines and fogging systems (Fairchild *et al.*, 2006)

** Manganese concentration as high as 20 ppm has not affected poultry health, but can have negative effects on water lines and fogging systems (Batal *et al.*, 2005)

4.4 Disposal of the Brine

At this location, there are two options for brine disposal: salt pans or back to the sea. Luckily the water at this coast is very rough and choppy. Disposing of the brine from SRWO into the sea should not lead to any environmental effects. The water will be concentrated in salt, but due to the rough water mixing the disposed water easily, it will not lead to negative environmental impacts. There are no new nutrients introduced back to the sea. Disposing of the brine from BRWO into the sea without post treatment introduces nutrients to the area that are typically not in high concentration, particularly nitrogen. This could lead to eutrophication, but due to the rough waters and small amount of water disposed as recovery can be higher for BRWO, environmental impacts are likely non-existent to minimal. Additionally, production for this RO unit will realistically be small-scale, which also helps reduce environmental impacts.

Using salt pans to dispose of the brine could lead to a profit if the salt was sold. However, although there is ample space in the Punta Blanku region to have large salt pans, the transport of the salt would a difficult problem, as the roads are in poor shape and the sea is too rough to dock a boat nearby. Additionally, Cargill has a very large salt production on the island. There may not be enough interest of people on the island to buy the salt as there is currently enough supply, and it is likely that the production would be too small-scale for Cargill to be interested in it. If the salt can be sold for profit, it would be an economical advantage for the Cooperation Punta Agua to use salt pans to dispose of the brine.

Another reason to use salt pans could be to create a nature reserve instead of selling the salt for profit. The natural habitat for flamingoes is typically large alkaline lakes, saline lakes, or estuarine lagoons that lack most vegetation. There are a lot of flamingoes on Bonaire compared to the rest of the world because the island provides these habitats. A salt pan with the brine could a good habitat for different wildlife, including flamingoes. Having a nature reserve could help with revitalizing the area and increasing tourism.

4.5 Electrical power needs

Electrical power needs are mostly dependent on TDS values of source water, as well as permeate production volume. BWRO requires less power than SWRO (Table 3). Based on the average wind speed, 50 m^3/day permeate from SWRO and up to 200 m^3/day permeate from BRWO is possible. However, considering that wind varies throughout the day and that an average does not capture daily and hourly fluctuations, it is expected that FreshWaterMill will work best for BWRO due to its significantly lower energy needs. At the minimum speed required for energy production from FreshWaterMill, it is enough to power 200 m^3/day permeate production from BWRO.

4.6 Energy Production or Lowering Energy Consumption

This section only applies to Punta Blanku Farms. The farm already participates in some energy conservation practices, such as turning off all power from 22:00 to 6:00. Based on current equipment, there are no large changes that can be made to further lower energy consumption. If FreshWaterMill is installed, on days that there is excess energy, it could be used at the farm. The farm uses approximately 25 – 30 kW per day, but approximately 3 to 4 times a month, feed is brought, which uses an extra 90 kW per time (360 kW per month) bringing the approximate monthly average to 1,170 kW (Kops, 2018). Diesel costs $0.80-$0.90 per liter and Punta Blanku farms uses approximately 1000 liters of diesel every 3 weeks. Maintenance for the generator is approximately $500 every month (Kops, 2018). Excess energy from the FreshWaterMill will vary every day, and some days it could cover all the electrical usage and some days it could cover some. Lowering the usage of the diesel generator lowers the cost and is more environmentally friendly. Less diesel would be used, maintenance costs could be lowered, and the life expectancy of the generator could be extended.

4.7 Costs

Investment costs were heavily dependent on permeate production amount, rather than water source (Table 3). It is likely that costs can be reduced for both SWRO and BWRO with design optimization. Additionally, permeate production can be increased over time and based on current water needs, 20 m^3/day should be adequate for the chicken farm as well as the small-scale hobby farmers, reducing initial investment costs. It is possible that Cooperation Punta Agua could receive some grants related to agriculture and renewable energy to fund initial investment costs.

5 Conclusion and Recommendations

A stable water supply that is not overpriced will help Punta Blanku Farms and part-time farmers and may invigorate the area and increase crop production beyond small farms towards a sustainable and economical feasible activity. Installing a reverse osmosis water treatment system will turn seawater or brackish groundwater into quality water that can be used for different agricultural purposes. Based on the preliminary results and model design, it is recommended to use the brackish groundwater as the water is filtered through the soil and brackish groundwater will cause less biofouling issues than the seawater, and BWRO can be powered easily by FreshWaterMill with renewable energy. Considering that at times the wind speed will be below the average of 7 m/s and extremely high diesel costs and how environmentally damaging it is, it is best if the power requirement of the RO system is as low as possible. If location 4 is used, new pipes should be used, as the current pipes may have iron deposits. If Cooperation Punta Agua prefers to use seawater, it is recommended to lower the recovery and schedule for more maintenance to clean the membranes. It is very important to note that this report only had preliminary lab results available, and more complete testing would be required prior to BWRO design and installation. It is recommended to measure the boron concentration and the saturation index to determine the complete set up for pre- and post-treatment. Since production is for a small-scale set up and there is a virtually unlimited supply of source water for either seawater or brackish groundwater, the recovery can be lowered for both water sources, which will lead to less fouling issues. For disposal of the brine, the simplest solution is to discard the water into the sea where the water is rough. However, if Cooperation Punta Agua is interested in using salt pans for either salt production or as a nature reserve, it is recommended to first speak to a representative of Cargill and gain knowledge on the creation and cost of salt pan creation. To save costs on diesel and to use green energy, Cooperation Punta Agua could use the FreshWaterMill coupled with the reverse osmosis installation which would mean there would be hardly any operation costs. Cooperation Punta Agua could sell the excess energy to Punta Blanku Farms, which would lower the electricity dependent on diesel for the operation of the farm. It could be sold at a decent price and lead to more green energy on the island, depending on grid expansion.

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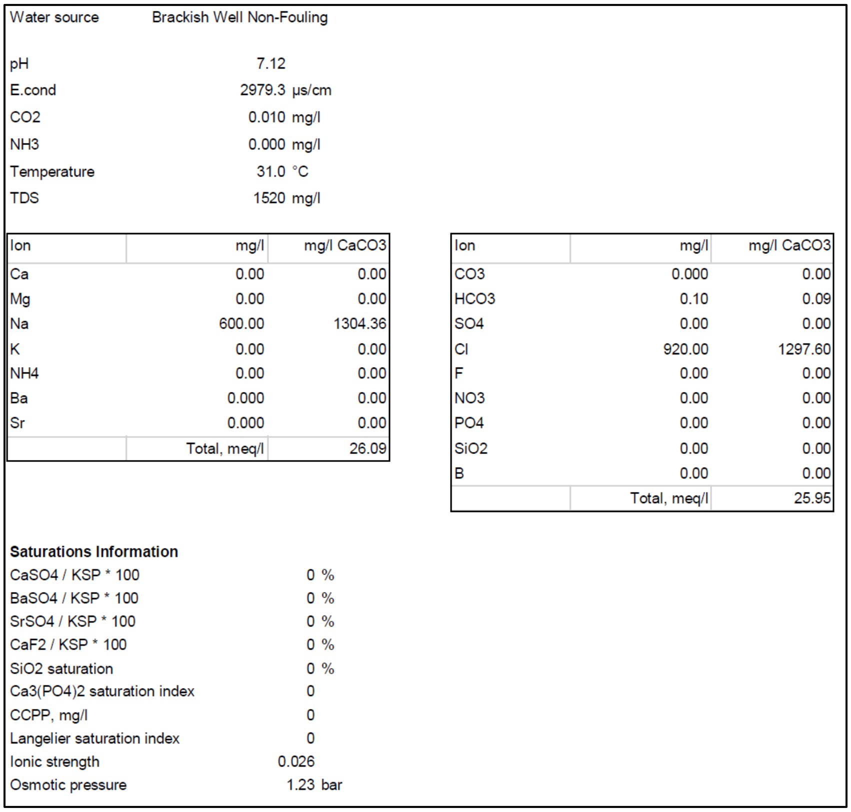
Appendix



Water source Brackish Well Non-Fouling

pH	7.12	
E.cond	2979.3	µs/cm
CO2	0.010	mg/l
NH3	0.000	mg/l
Temperature	31.0	°C
TDS	1520	mg/l

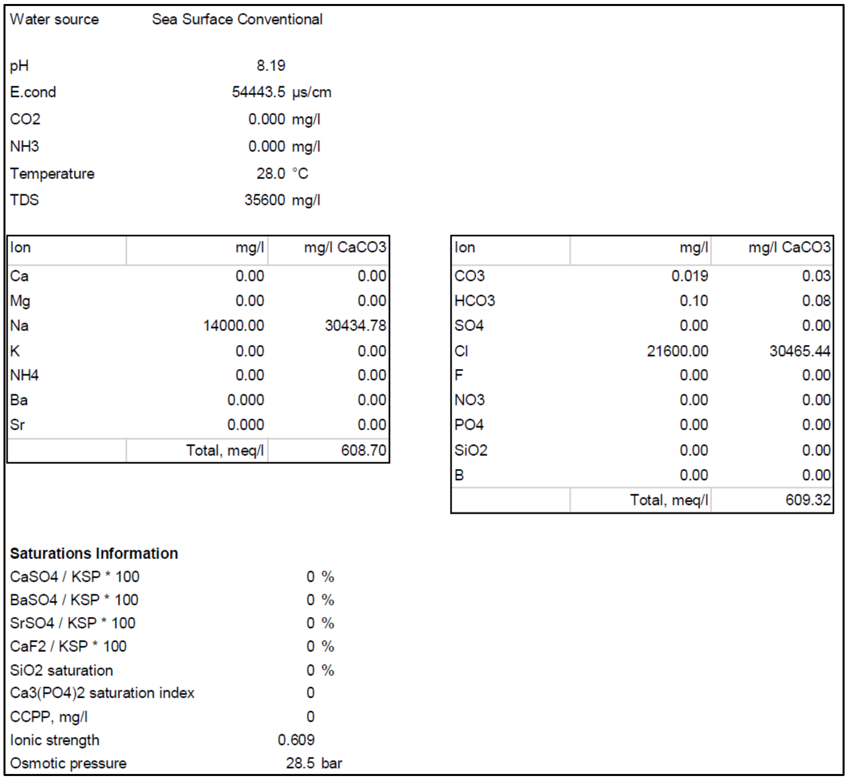
Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	600.00	1304.36
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	26.09

Ion	mg/l	mg/l CaCO3
CO3	0.000	0.00
HCO3	0.10	0.09
SO4	0.00	0.00
Cl	920.00	1297.60
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	25.95

Saturations Information

CaSO4 / KSP * 100	0	%
BaSO4 / KSP * 100	0	%
SrSO4 / KSP * 100	0	%
CaF2 / KSP * 100	0	%
SiO2 saturation	0	%
Ca3(PO4)2 saturation index	0	
CCPP, mg/l	0	
Langelier saturation index	0	
Ionic strength	0.026	
Osmotic pressure	1.23	bar

Figure A 1. Brackish feed water for BWRO in IMSDesigns. Na^+ and Cl^- concentrations are based on electrical conductivity from sample 4 (brackish groundwater).



Water source	Sea Surface Conventional	
pH	8.19	
E.cond	54443.5	µs/cm
CO2	0.000	mg/l
NH3	0.000	mg/l
Temperature	28.0	°C
TDS	35600	mg/l

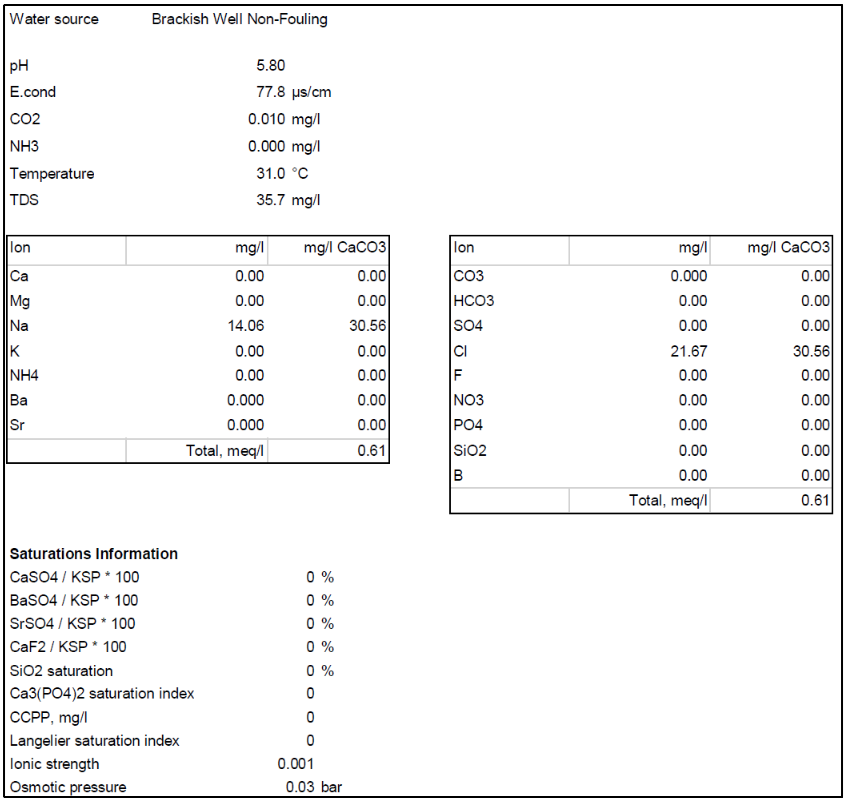
Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	14000.00	30434.78
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	608.70

Ion	mg/l	mg/l CaCO3
CO3	0.019	0.03
HCO3	0.10	0.08
SO4	0.00	0.00
Cl	21600.00	30465.44
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	609.32

Saturations Information

CaSO4 / KSP * 100	0	%
BaSO4 / KSP * 100	0	%
SrSO4 / KSP * 100	0	%
CaF2 / KSP * 100	0	%
SiO2 saturation	0	%
Ca3(PO4)2 saturation index	0	
CCPP, mg/l	0	
Ionic strength	0.609	
Osmotic pressure	28.5	bar

Figure A 2. Seawater feed for SWRO in IMSDesigns. Na^+ and Cl^- concentrations are based on electrical conductivity from sample 3 (surface seawater).



Water source	Brackish Well Non-Fouling

pH	5.80	
E.cond	77.8	µs/cm
CO2	0.010	mg/l
NH3	0.000	mg/l
Temperature	31.0	°C
TDS	35.7	mg/l

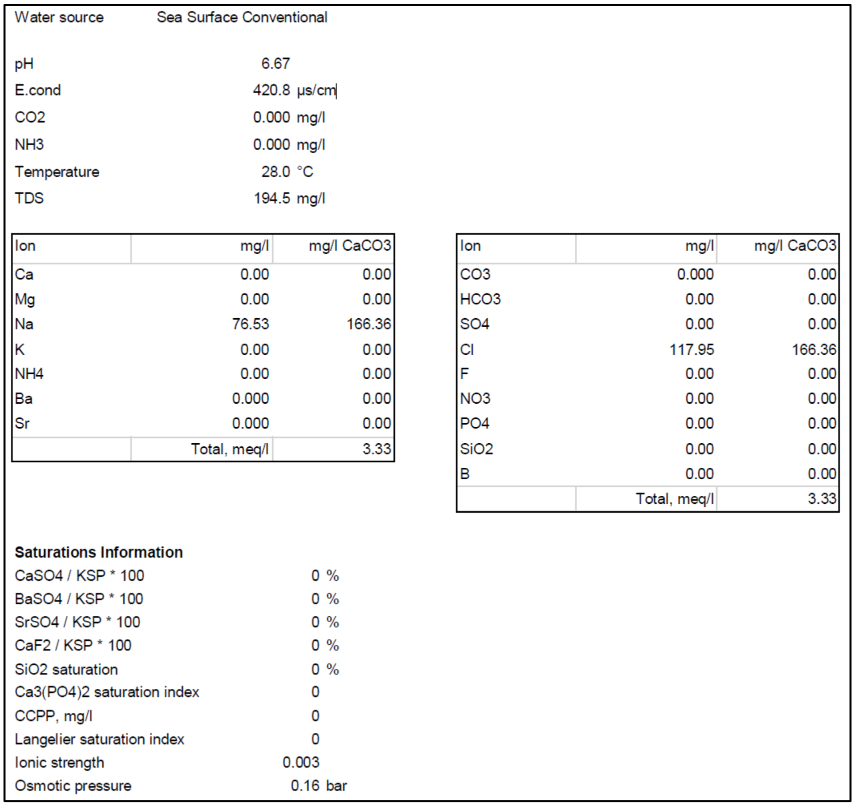
Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	14.06	30.56
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	0.61

Ion	mg/l	mg/l CaCO3
CO3	0.000	0.00
HCO3	0.00	0.00
SO4	0.00	0.00
Cl	21.67	30.56
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	0.61

Saturations Information

CaSO4 / KSP * 100	0	%
BaSO4 / KSP * 100	0	%
SrSO4 / KSP * 100	0	%
CaF2 / KSP * 100	0	%
SiO2 saturation	0	%
Ca3(PO4)2 saturation index	0	
CCPP, mg/l	0	
Langelier saturation index	0	
Ionic strength	0.001	
Osmotic pressure	0.03	bar

Figure A 3. Permeate water quality characteristics from 50 m^3/day permeate production from BWRO from sample 4 in IMSDesigns



Water source Sea Surface Conventional

pH 6.67
E.cond 420.8 µs/cm
CO2 0.000 mg/l
NH3 0.000 mg/l
Temperature 28.0 °C
TDS 194.5 mg/l

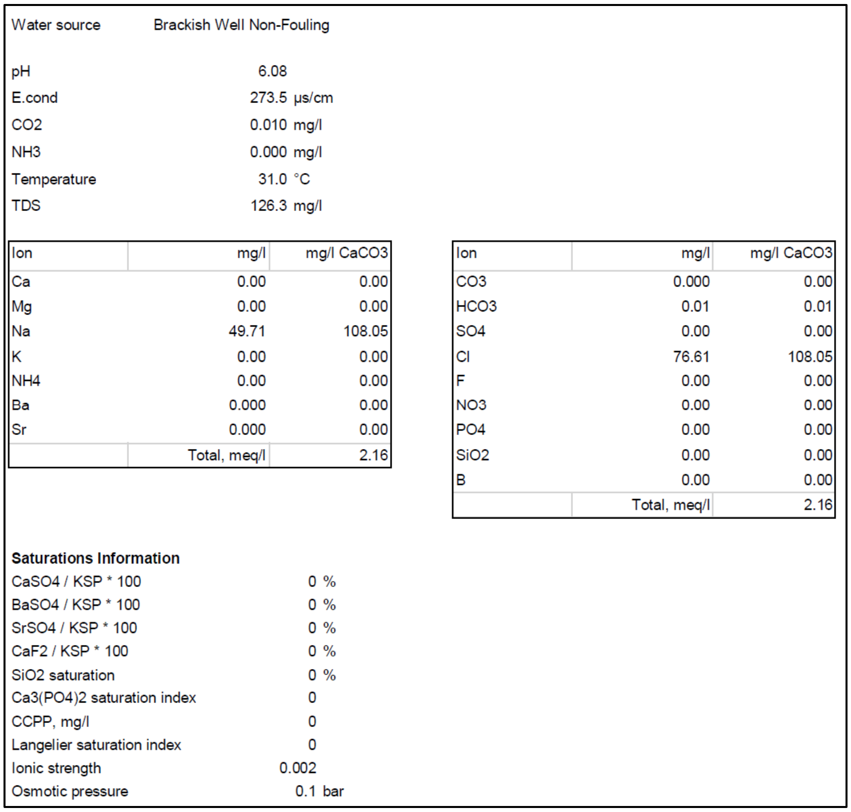
Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	76.53	166.36
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	3.33

Ion	mg/l	mg/l CaCO3
CO3	0.000	0.00
HCO3	0.00	0.00
SO4	0.00	0.00
Cl	117.95	166.36
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	3.33

Saturations Information

CaSO4 / KSP * 100	0 %
BaSO4 / KSP * 100	0 %
SrSO4 / KSP * 100	0 %
CaF2 / KSP * 100	0 %
SiO2 saturation	0 %
Ca3(PO4)2 saturation index	0
CCPP, mg/l	0
Langelier saturation index	0
Ionic strength	0.003
Osmotic pressure	0.16 bar

Figure A 4. Permeate water quality characteristics from 50 m^3/day permeate production from SWRO from sample 3 in IMSDesigns



Water source	Brackish Well Non-Fouling	
pH	6.08	
E.cond	273.5	μs/cm
CO2	0.010	mg/l
NH3	0.000	mg/l
Temperature	31.0	°C
TDS	126.3	mg/l

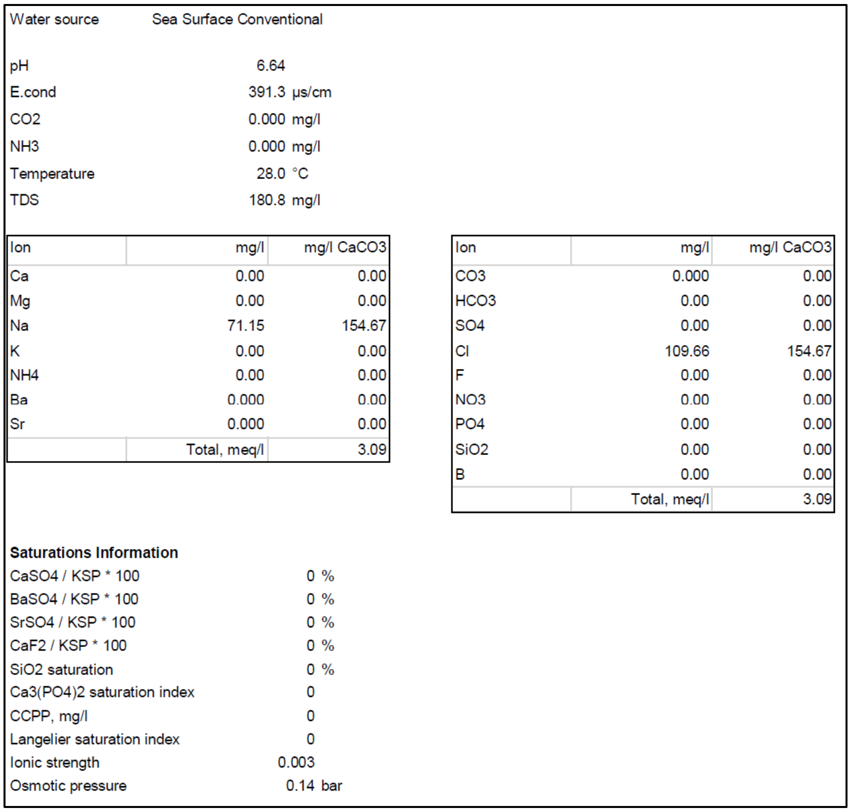
Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	49.71	108.05
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	2.16

Ion	mg/l	mg/l CaCO3
CO3	0.000	0.00
HCO3	0.01	0.01
SO4	0.00	0.00
Cl	76.61	108.05
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	2.16

Saturations Information

CaSO4 / KSP * 100	0	%
BaSO4 / KSP * 100	0	%
SrSO4 / KSP * 100	0	%
CaF2 / KSP * 100	0	%
SiO2 saturation	0	%
Ca3(PO4)2 saturation index	0	
CCPP, mg/l	0	
Langelier saturation index	0	
Ionic strength	0.002	
Osmotic pressure	0.1	bar

Figure A 5. Permeate water quality characteristics from 200 m^3/day permeate production from BWRO from sample 4 in IMSDesigns



Water source	Sea Surface Conventional
pH	6.64
E.cond	391.3 µs/cm
CO2	0.000 mg/l
NH3	0.000 mg/l
Temperature	28.0 °C
TDS	180.8 mg/l

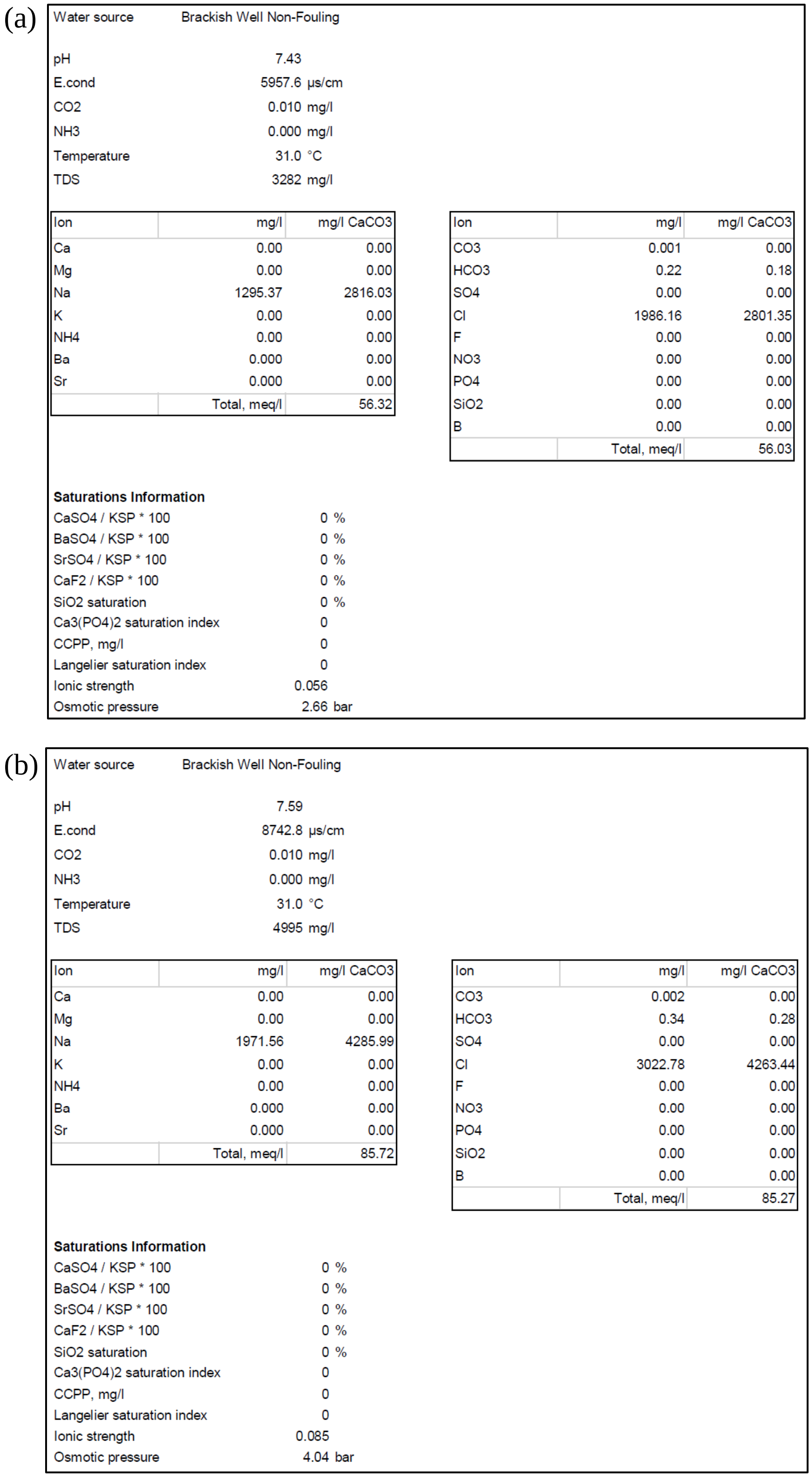
Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	71.15	154.67
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	3.09

Ion	mg/l	mg/l CaCO3
CO3	0.000	0.00
HCO3	0.00	0.00
SO4	0.00	0.00
Cl	109.66	154.67
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	3.09

Saturations Information

CaSO4 / KSP * 100	0 %
BaSO4 / KSP * 100	0 %
SrSO4 / KSP * 100	0 %
CaF2 / KSP * 100	0 %
SiO2 saturation	0 %
Ca3(PO4)2 saturation index	0
CCPP, mg/l	0
Langelier saturation index	0
Ionic strength	0.003
Osmotic pressure	0.14 bar

Figure A 6. Permeate water quality characteristics from 200 m^3/day permeate production SWRO from sample 3 in IMSDesigns



(a)

Water source Brackish Well Non-Fouling

pH 7.43
E.cond 5957.6 µs/cm
CO2 0.010 mg/l
NH3 0.000 mg/l
Temperature 31.0 °C
TDS 3282 mg/l

Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	1295.37	2816.03
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	56.32

Ion	mg/l	mg/l CaCO3
CO3	0.001	0.00
HCO3	0.22	0.18
SO4	0.00	0.00
Cl	1986.16	2801.35
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	56.03

Saturations Information

CaSO4 / KSP * 100	0 %
BaSO4 / KSP * 100	0 %
SrSO4 / KSP * 100	0 %
CaF2 / KSP * 100	0 %
SiO2 saturation	0 %
Ca3(PO4)2 saturation index	0
CCPP, mg/l	0
Langelier saturation index	0
Ionic strength	0.056
Osmotic pressure	2.66 bar

(b)

Water source Brackish Well Non-Fouling

pH 7.59
E.cond 8742.8 µs/cm
CO2 0.010 mg/l
NH3 0.000 mg/l
Temperature 31.0 °C
TDS 4995 mg/l

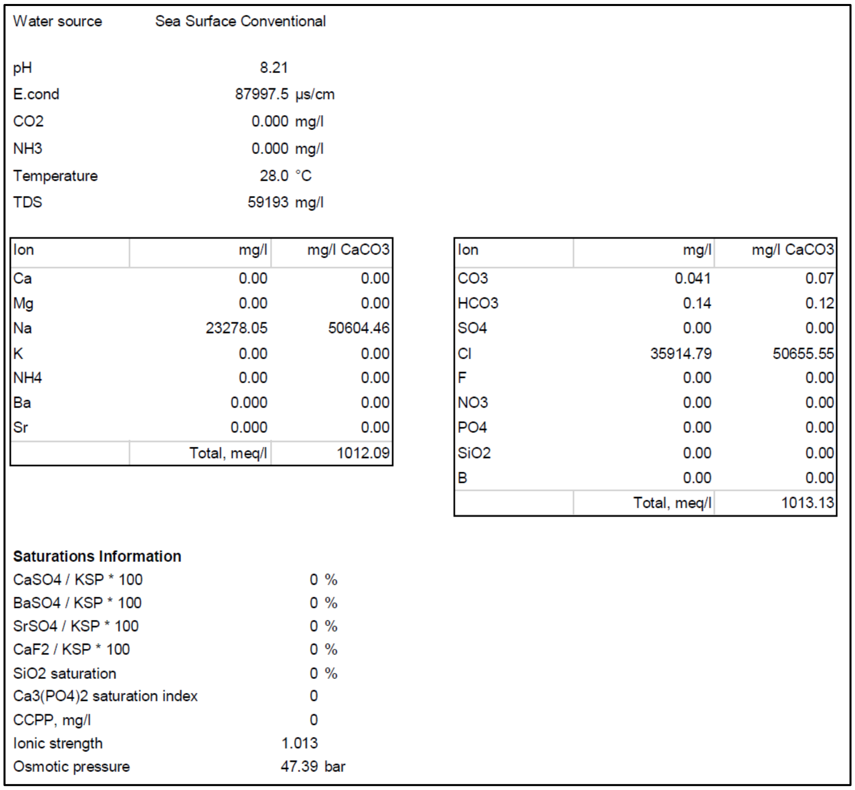
Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	1971.56	4285.99
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	85.72

Ion	mg/l	mg/l CaCO3
CO3	0.002	0.00
HCO3	0.34	0.28
SO4	0.00	0.00
Cl	3022.78	4263.44
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	85.27

Saturations Information

CaSO4 / KSP * 100	0 %
BaSO4 / KSP * 100	0 %
SrSO4 / KSP * 100	0 %
CaF2 / KSP * 100	0 %
SiO2 saturation	0 %
Ca3(PO4)2 saturation index	0
CCPP, mg/l	0
Langelier saturation index	0
Ionic strength	0.085
Osmotic pressure	4.04 bar

Figure A 7. Water quality characteristics from concentrate in (a) first stage and (b) second stage 50 m^3/day permeate production BWRO from Sample 4 in IMSDesigns



Water source	Sea Surface Conventional
pH	8.21
E.cond	87997.5 µs/cm
CO2	0.000 mg/l
NH3	0.000 mg/l
Temperature	28.0 °C
TDS	59193 mg/l

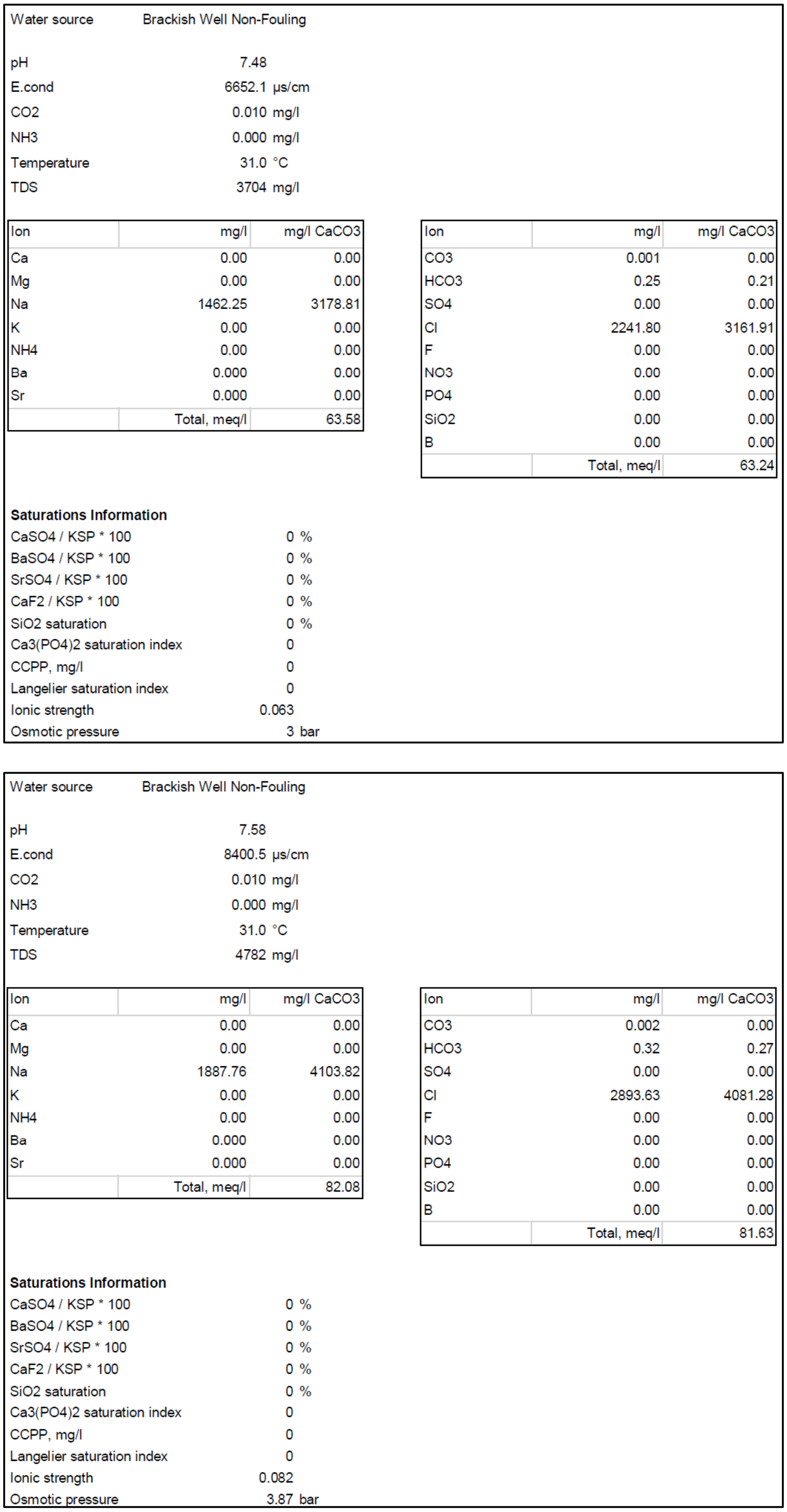
Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	23278.05	50604.46
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	1012.09

Ion	mg/l	mg/l CaCO3
CO3	0.041	0.07
HCO3	0.14	0.12
SO4	0.00	0.00
Cl	35914.79	50655.55
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	1013.13

Saturations Information

CaSO4 / KSP * 100	0 %
BaSO4 / KSP * 100	0 %
SrSO4 / KSP * 100	0 %
CaF2 / KSP * 100	0 %
SiO2 saturation	0 %
Ca3(PO4)2 saturation index	0
CCPP, mg/l	0
Ionic strength	1.013
Osmotic pressure	47.39 bar

Figure A 8. Water quality characteristics from concentrate in 50 m^3/day permeate production SWRO from Sample 3 in IMSDesigns



(a)

Water source Brackish Well Non-Fouling

pH 7.48
E.cond 6652.1 µs/cm
CO2 0.010 mg/l
NH3 0.000 mg/l
Temperature 31.0 °C
TDS 3704 mg/l

Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	1462.25	3178.81
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	63.58

Ion	mg/l	mg/l CaCO3
CO3	0.001	0.00
HCO3	0.25	0.21
SO4	0.00	0.00
Cl	2241.80	3161.91
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	63.24

Saturations Information

CaSO4 / KSP * 100	0 %
BaSO4 / KSP * 100	0 %
SrSO4 / KSP * 100	0 %
CaF2 / KSP * 100	0 %
SiO2 saturation	0 %
Ca3(PO4)2 saturation index	0
CCPP, mg/l	0
Langelier saturation index	0
Ionic strength	0.063
Osmotic pressure	3 bar

(b)

Water source Brackish Well Non-Fouling

pH 7.58
E.cond 8400.5 µs/cm
CO2 0.010 mg/l
NH3 0.000 mg/l
Temperature 31.0 °C
TDS 4782 mg/l

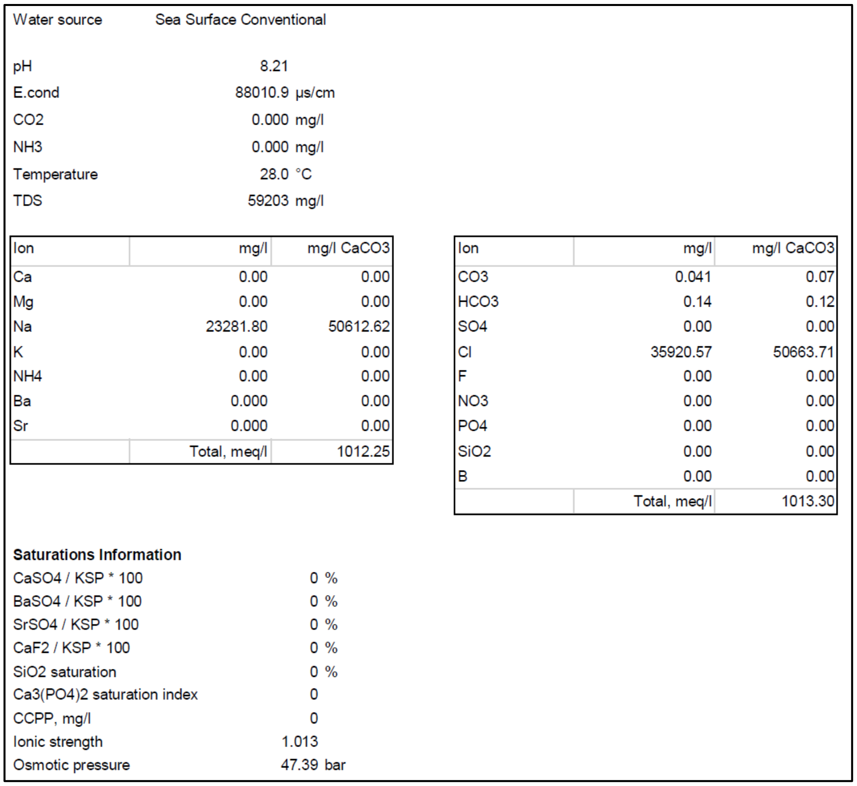
Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	1887.76	4103.82
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	82.08

Ion	mg/l	mg/l CaCO3
CO3	0.002	0.00
HCO3	0.32	0.27
SO4	0.00	0.00
Cl	2893.63	4081.28
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	81.63

Saturations Information

CaSO4 / KSP * 100	0 %
BaSO4 / KSP * 100	0 %
SrSO4 / KSP * 100	0 %
CaF2 / KSP * 100	0 %
SiO2 saturation	0 %
Ca3(PO4)2 saturation index	0
CCPP, mg/l	0
Langelier saturation index	0
Ionic strength	0.082
Osmotic pressure	3.87 bar

Figure A 9. Water quality characteristics from concentrate in (a) first stage and (b) second stage 200 m^3/day permeate production BWRO from Sample 4 in IMSDesigns



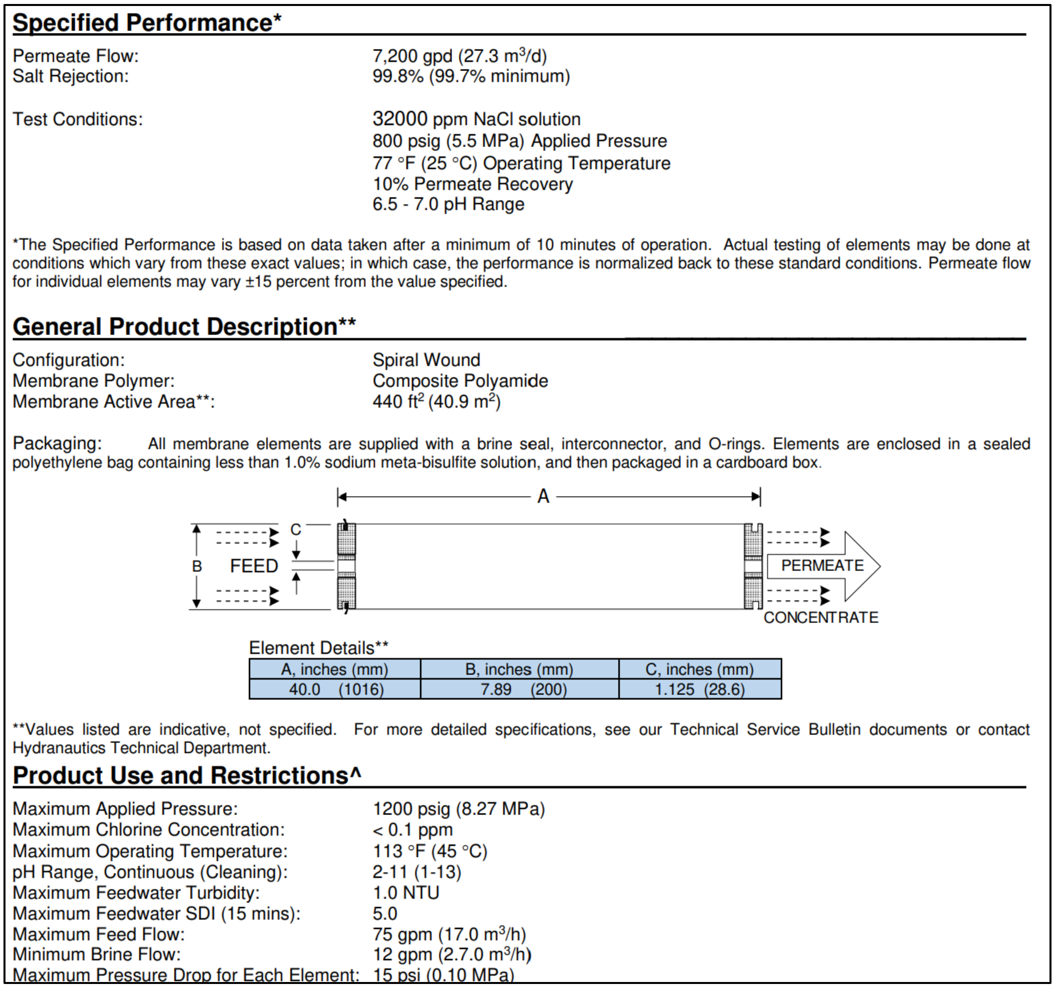
Water source	Sea Surface Conventional
pH	8.21
E.cond	88010.9 µs/cm
CO2	0.000 mg/l
NH3	0.000 mg/l
Temperature	28.0 °C
TDS	59203 mg/l

Ion	mg/l	mg/l CaCO3
Ca	0.00	0.00
Mg	0.00	0.00
Na	23281.80	50612.62
K	0.00	0.00
NH4	0.00	0.00
Ba	0.000	0.00
Sr	0.000	0.00
	Total, meq/l	1012.25

Ion	mg/l	mg/l CaCO3
CO3	0.041	0.07
HCO3	0.14	0.12
SO4	0.00	0.00
Cl	35920.57	50663.71
F	0.00	0.00
NO3	0.00	0.00
PO4	0.00	0.00
SiO2	0.00	0.00
B	0.00	0.00
	Total, meq/l	1013.30

Saturations Information	
CaSO4 / KSP * 100	0 %
BaSO4 / KSP * 100	0 %
SrSO4 / KSP * 100	0 %
CaF2 / KSP * 100	0 %
SiO2 saturation	0 %
Ca3(PO4)2 saturation index	0
CCPP, mg/l	0
Ionic strength	1.013
Osmotic pressure	47.39 bar

Figure A 10. Water quality characteristics from concentrate in 200 m^3/day permeate production SWRO from Sample 3 in IMSDesigns



Specified Performance*

Permeate Flow:	7,200 gpd (27.3 m^3/d)
Salt Rejection:	99.8% (99.7% minimum)
Test Conditions:	32000 ppm NaCl solution 800 psig (5.5 MPa) Applied Pressure 77 °F (25 °C) Operating Temperature 10% Permeate Recovery 6.5 - 7.0 pH Range

*The Specified Performance is based on data taken after a minimum of 10 minutes of operation. Actual testing of elements may be done at conditions which vary from these exact values; in which case, the performance is normalized back to these standard conditions. Permeate flow for individual elements may vary ±15 percent from the value specified.

General Product Description**

Configuration:	Spiral Wound
Membrane Polymer:	Composite Polyamide
Membrane Active Area**:	440 ft^2 (40.9 m^2)

Packaging: All membrane elements are supplied with a brine seal, interconnector, and O-rings. Elements are enclosed in a sealed polyethylene bag containing less than 1.0% sodium meta-bisulfite solution, and then packaged in a cardboard box.

Element Details**

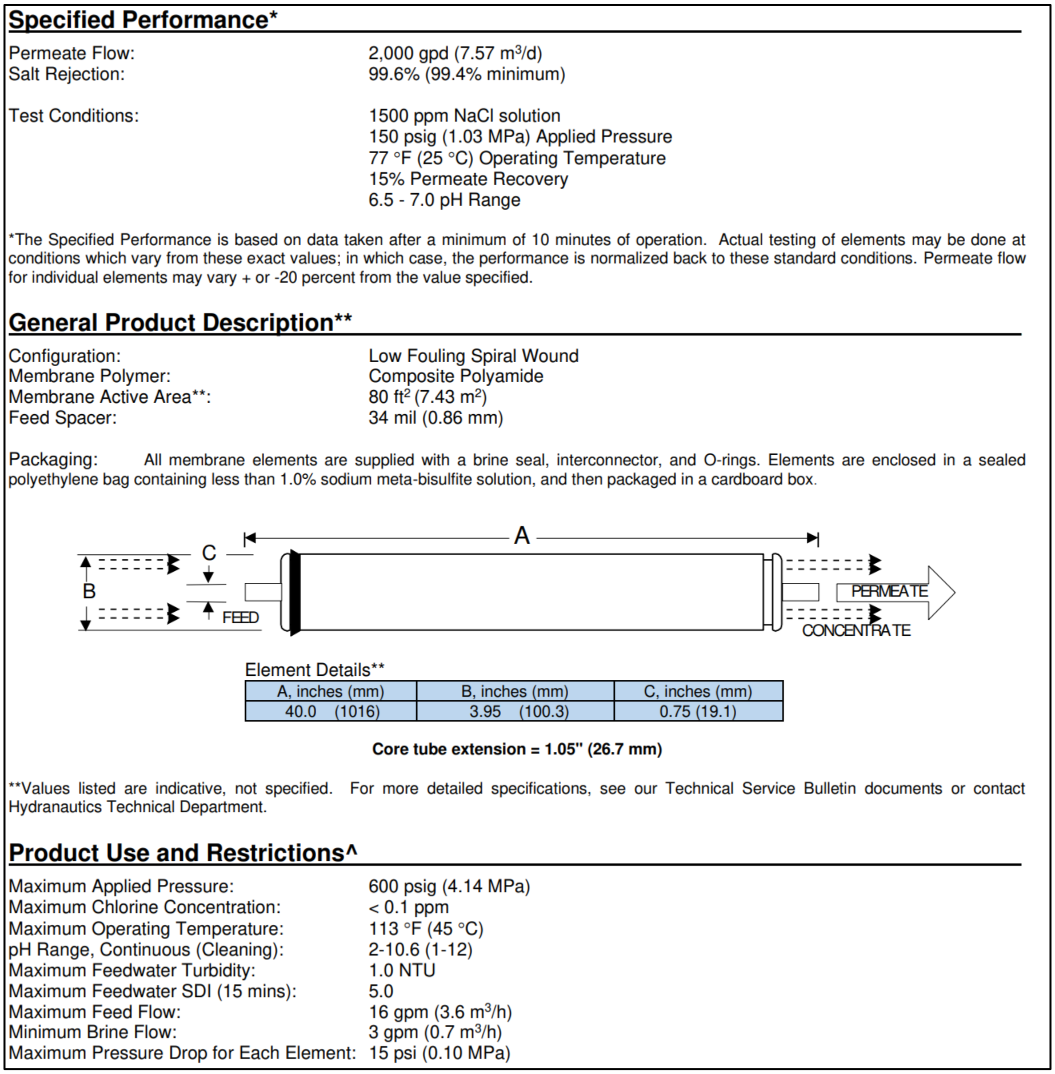
A, inches (mm)	B, inches (mm)	C, inches (mm)
40.0 (1016)	7.89 (200)	1.125 (28.6)

**Values listed are indicative, not specified. For more detailed specifications, see our Technical Service Bulletin documents or contact Hydranautics Technical Department.

Product Use and Restrictions^

Maximum Applied Pressure:	1200 psig (8.27 MPa)
Maximum Chlorine Concentration:	< 0.1 ppm
Maximum Operating Temperature:	113 °F (45 °C)
pH Range, Continuous (Cleaning):	2-11 (1-13)
Maximum Feedwater Turbidity:	1.0 NTU
Maximum Feedwater SDI (15 mins):	5.0
Maximum Feed Flow:	75 gpm (17.0 m^3/h)
Minimum Brine Flow:	12 gpm (2.7.0 m^3/h)
Maximum Pressure Drop for Each Element:	15 psi (0.10 MPa)

Figure A 11. Element specification sheet for SWC4 MAX, the element chosen for SWRO, both 50 m^3/day and 200 m^3/day permeate production (Hydranautics, 2023)



Specified Performance*

Permeate Flow:	2,000 gpd (7.57 m³/d)
Salt Rejection:	99.6% (99.4% minimum)
Test Conditions:	1500 ppm NaCl solution 150 psig (1.03 MPa) Applied Pressure 77 °F (25 °C) Operating Temperature 15% Permeate Recovery 6.5 - 7.0 pH Range

*The Specified Performance is based on data taken after a minimum of 10 minutes of operation. Actual testing of elements may be done at conditions which vary from these exact values; in which case, the performance is normalized back to these standard conditions. Permeate flow for individual elements may vary + or -20 percent from the value specified.

General Product Description**

Configuration:	Low Fouling Spiral Wound
Membrane Polymer:	Composite Polyamide
Membrane Active Area**:	80 ft² (7.43 m²)
Feed Spacer:	34 mil (0.86 mm)

Packaging: All membrane elements are supplied with a brine seal, interconnector, and O-rings. Elements are enclosed in a sealed polyethylene bag containing less than 1.0% sodium meta-bisulfite solution, and then packaged in a cardboard box.

Element Details**

A, inches (mm)	B, inches (mm)	C, inches (mm)
40.0 (1016)	3.95 (100.3)	0.75 (19.1)

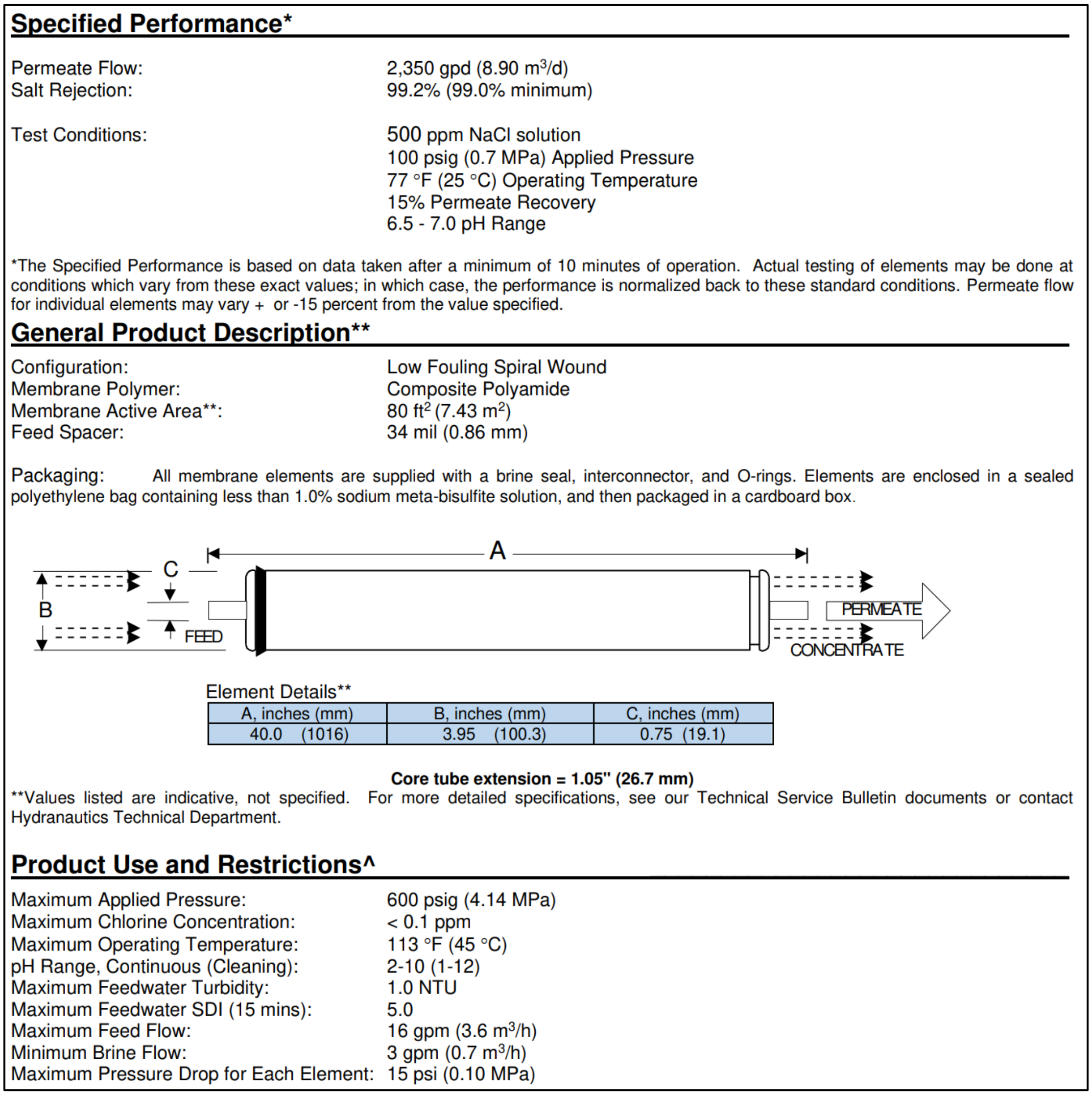
Core tube extension = 1.05" (26.7 mm)

**Values listed are indicative, not specified. For more detailed specifications, see our Technical Service Bulletin documents or contact Hydranautics Technical Department.

Product Use and Restrictions^

Maximum Applied Pressure:	600 psig (4.14 MPa)
Maximum Chlorine Concentration:	< 0.1 ppm
Maximum Operating Temperature:	113 °F (45 °C)
pH Range, Continuous (Cleaning):	2-10.6 (1-12)
Maximum Feedwater Turbidity:	1.0 NTU
Maximum Feedwater SDI (15 mins):	5.0
Maximum Feed Flow:	16 gpm (3.6 m³/h)
Minimum Brine Flow:	3 gpm (0.7 m³/h)
Maximum Pressure Drop for Each Element:	15 psi (0.10 MPa)

Figure A 12. Element specification sheet for ESPA2-LD-4040, the element chosen for BWRO, 50 m^3/day permeate production (Hydranautics, 2023)



Specified Performance*

Permeate Flow:	2,350 gpd (8.90 m^3/d)
Salt Rejection:	99.2% (99.0% minimum)
Test Conditions:	500 ppm NaCl solution 100 psig (0.7 MPa) Applied Pressure 77 °F (25 °C) Operating Temperature 15% Permeate Recovery 6.5 - 7.0 pH Range

*The Specified Performance is based on data taken after a minimum of 10 minutes of operation. Actual testing of elements may be done at conditions which vary from these exact values; in which case, the performance is normalized back to these standard conditions. Permeate flow for individual elements may vary + or -15 percent from the value specified.

General Product Description**

Configuration:	Low Fouling Spiral Wound
Membrane Polymer:	Composite Polyamide
Membrane Active Area**:	80 ft^2 (7.43 m^2)
Feed Spacer:	34 mil (0.86 mm)

Packaging: All membrane elements are supplied with a brine seal, interconnector, and O-rings. Elements are enclosed in a sealed polyethylene bag containing less than 1.0% sodium meta-bisulfite solution, and then packaged in a cardboard box.

Element Details**

A, inches (mm)	B, inches (mm)	C, inches (mm)
40.0 (1016)	3.95 (100.3)	0.75 (19.1)

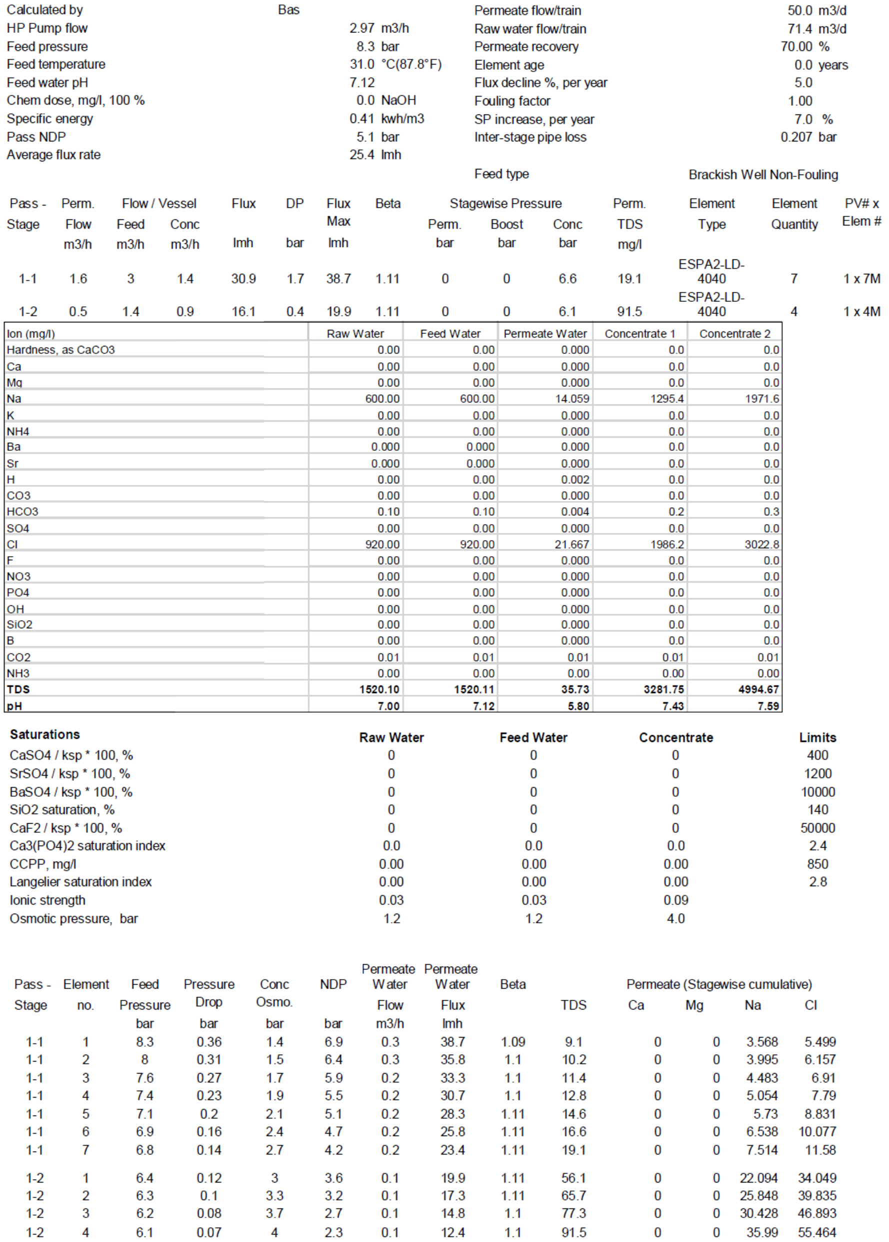
Core tube extension = 1.05" (26.7 mm)

**Values listed are indicative, not specified. For more detailed specifications, see our Technical Service Bulletin documents or contact Hydranautics Technical Department.

Product Use and Restrictions^

Maximum Applied Pressure:	600 psig (4.14 MPa)
Maximum Chlorine Concentration:	< 0.1 ppm
Maximum Operating Temperature:	113 °F (45 °C)
pH Range, Continuous (Cleaning):	2-10 (1-12)
Maximum Feedwater Turbidity:	1.0 NTU
Maximum Feedwater SDI (15 mins):	5.0
Maximum Feed Flow:	16 gpm (3.6 m^3/h)
Minimum Brine Flow:	3 gpm (0.7 m^3/h)
Maximum Pressure Drop for Each Element:	15 psi (0.10 MPa)

Figure A 13. Element specification sheet for ESPA4-LD-4040, the element chosen for BWRO, 200 m^3/day permeate production (Hydranautics, 2023)



Calculated by	Bas	Permeate flow/train	50.0 m3/d
HP Pump flow	2.97 m3/h	Raw water flow/train	71.4 m3/d
Feed pressure	8.3 bar	Permeate recovery	70.00 %
Feed temperature	31.0 °C(87.8°F)	Element age	0.0 years
Feed water pH	7.12	Flux decline %, per year	5.0
Chem dose, mg/l, 100 %	0.0 NaOH	Fouling factor	1.00
Specific energy	0.41 kwh/m3	SP increase, per year	7.0 %
Pass NDP	5.1 bar	Inter-stage pipe loss	0.207 bar
Average flux rate	25.4 lmh		
		Feed type	Brackish Well Non-Fouling

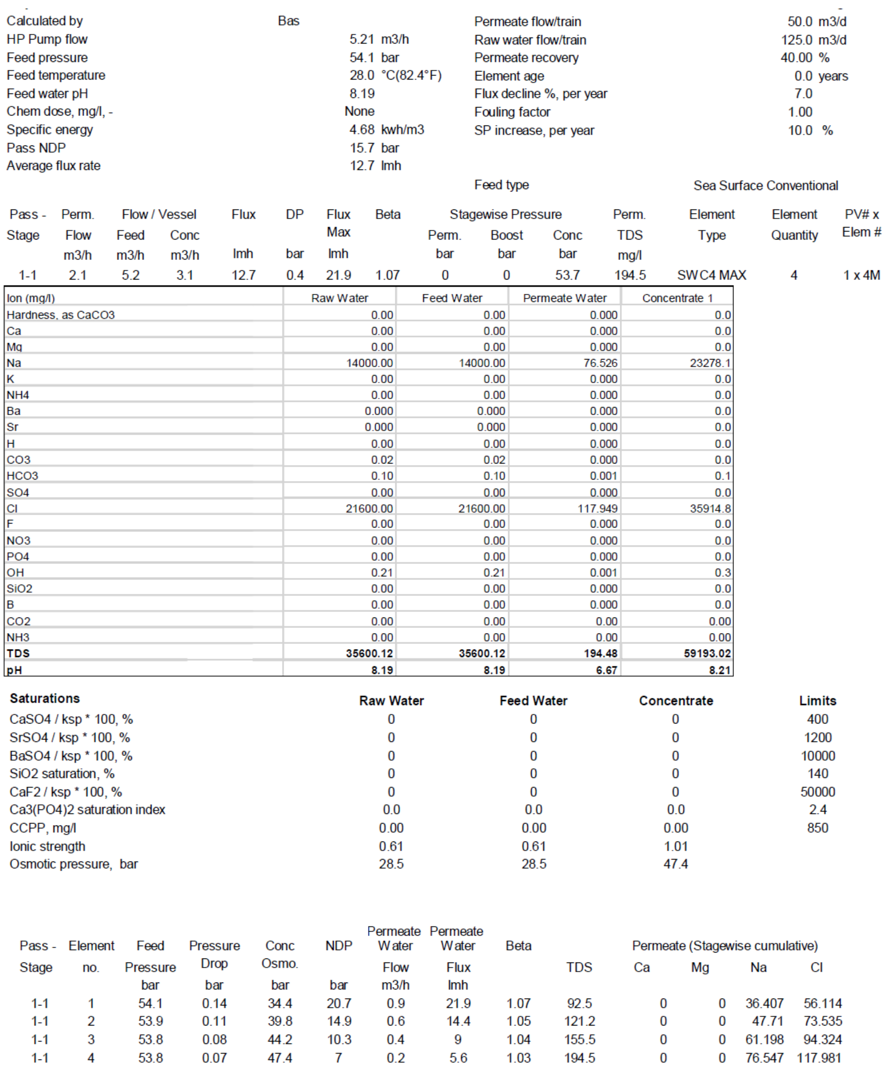
Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	1.6	3	1.4	30.9	1.7	38.7	1.11	0	0	6.6	19.1	ESPA2-LD-4040	7	1 x 7M
1-2	0.5	1.4	0.9	16.1	0.4	19.9	1.11	0	0	6.1	91.5	ESPA2-LD-4040	4	1 x 4M

Ion (mg/l)	Raw Water	Feed Water	Permeate Water	Concentrate 1	Concentrate 2
Hardness, as CaCO3	0.00	0.00	0.000	0.0	0.0
Ca	0.00	0.00	0.000	0.0	0.0
Mg	0.00	0.00	0.000	0.0	0.0
Na	600.00	600.00	14.059	1295.4	1971.6
K	0.00	0.00	0.000	0.0	0.0
NH4	0.00	0.00	0.000	0.0	0.0
Ba	0.000	0.000	0.000	0.0	0.0
Sr	0.000	0.000	0.000	0.0	0.0
H	0.00	0.00	0.002	0.0	0.0
CO3	0.00	0.00	0.000	0.0	0.0
HCO3	0.10	0.10	0.004	0.2	0.3
SO4	0.00	0.00	0.000	0.0	0.0
Cl	920.00	920.00	21.667	1986.2	3022.8
F	0.00	0.00	0.000	0.0	0.0
NO3	0.00	0.00	0.000	0.0	0.0
PO4	0.00	0.00	0.000	0.0	0.0
OH	0.00	0.00	0.000	0.0	0.0
SiO2	0.00	0.00	0.000	0.0	0.0
B	0.00	0.00	0.000	0.0	0.0
CO2	0.01	0.01	0.01	0.01	0.01
NH3	0.00	0.00	0.00	0.00	0.00
TDS	**1520.10**	**1520.11**	**35.73**	**3281.75**	**4994.67**
pH	**7.00**	**7.12**	**5.80**	**7.43**	**7.59**

Saturations	**Raw Water**	**Feed Water**	**Concentrate**	**Limits**
CaSO4 / ksp * 100, %	0	0	0	400
SrSO4 / ksp * 100, %	0	0	0	1200
BaSO4 / ksp * 100, %	0	0	0	10000
SiO2 saturation, %	0	0	0	140
CaF2 / ksp * 100, %	0	0	0	50000
Ca3(PO4)2 saturation index	0.0	0.0	0.0	2.4
CCPP, mg/l	0.00	0.00	0.00	850
Langelier saturation index	0.00	0.00	0.00	2.8
Ionic strength	0.03	0.03	0.09	
Osmotic pressure, bar	1.2	1.2	4.0	

Pass - Stage	Element no.	Feed Pressure bar	Pressure Drop bar	Conc Osmo. bar	NDP bar	Permeate Water Flow m3/h	Permeate Water Flux lmh	Beta	TDS	Permeate (Stagewise cumulative) Ca	Mg	Na	Cl
1-1	1	8.3	0.36	1.4	6.9	0.3	38.7	1.09	9.1	0	0	3.568	5.499
1-1	2	8	0.31	1.5	6.4	0.3	35.8	1.1	10.2	0	0	3.995	6.157
1-1	3	7.6	0.27	1.7	5.9	0.2	33.3	1.1	11.4	0	0	4.483	6.91
1-1	4	7.4	0.23	1.9	5.5	0.2	30.7	1.1	12.8	0	0	5.054	7.79
1-1	5	7.1	0.2	2.1	5.1	0.2	28.3	1.11	14.6	0	0	5.73	8.831
1-1	6	6.9	0.16	2.4	4.7	0.2	25.8	1.11	16.6	0	0	6.538	10.077
1-1	7	6.8	0.14	2.7	4.2	0.2	23.4	1.11	19.1	0	0	7.514	11.58
1-2	1	6.4	0.12	3	3.6	0.1	19.9	1.11	56.1	0	0	22.094	34.049
1-2	2	6.3	0.1	3.3	3.2	0.1	17.3	1.11	65.7	0	0	25.848	39.835
1-2	3	6.2	0.08	3.7	2.7	0.1	14.8	1.1	77.3	0	0	30.428	46.893
1-2	4	6.1	0.07	4	2.3	0.1	12.4	1.1	91.5	0	0	35.99	55.464

Figure A 14. Basic RO design information for 50 m^3/day permeate production for BWRO in IMSDesigns



Calculated by	Bas	Permeate flow/train	50.0 m3/d
HP Pump flow	5.21 m3/h	Raw water flow/train	125.0 m3/d
Feed pressure	54.1 bar	Permeate recovery	40.00 %
Feed temperature	28.0 °C(82.4°F)	Element age	0.0 years
Feed water pH	8.19	Flux decline %, per year	7.0
Chem dose, mg/l, -	None	Fouling factor	1.00
Specific energy	4.68 kwh/m3	SP increase, per year	10.0 %
Pass NDP	15.7 bar		
Average flux rate	12.7 lmh		
		Feed type	Sea Surface Conventional

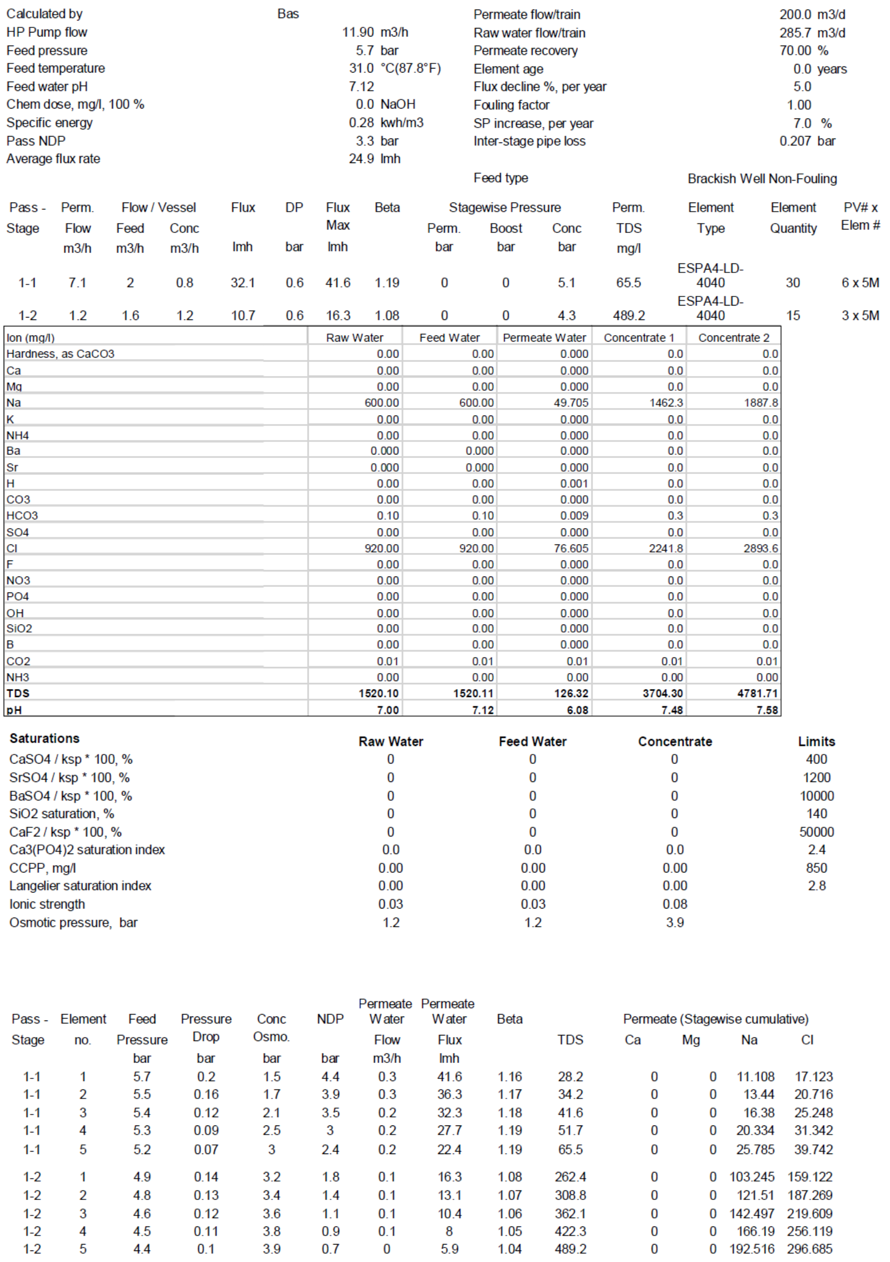
Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	2.1	5.2	3.1	12.7	0.4	21.9	1.07	0	0	53.7	194.5	SWC4 MAX	4	1 x 4M

Ion (mg/l)	Raw Water	Feed Water	Permeate Water	Concentrate 1
Hardness, as CaCO3	0.00	0.00	0.000	0.0
Ca	0.00	0.00	0.000	0.0
Mg	0.00	0.00	0.000	0.0
Na	14000.00	14000.00	76.526	23278.1
K	0.00	0.00	0.000	0.0
NH4	0.00	0.00	0.000	0.0
Ba	0.000	0.000	0.000	0.0
Sr	0.000	0.000	0.000	0.0
H	0.00	0.00	0.000	0.0
CO3	0.02	0.02	0.000	0.0
HCO3	0.10	0.10	0.001	0.1
SO4	0.00	0.00	0.000	0.0
Cl	21600.00	21600.00	117.949	35914.8
F	0.00	0.00	0.000	0.0
NO3	0.00	0.00	0.000	0.0
PO4	0.00	0.00	0.000	0.0
OH	0.21	0.21	0.001	0.3
SiO2	0.00	0.00	0.000	0.0
B	0.00	0.00	0.000	0.0
CO2	0.00	0.00	0.00	0.00
NH3	0.00	0.00	0.00	0.00
TDS	**35600.12**	**35600.12**	**194.48**	**59193.02**
pH	**8.19**	**8.19**	**6.67**	**8.21**

Saturations	**Raw Water**	**Feed Water**	**Concentrate**	**Limits**
CaSO4 / ksp * 100, %	0	0	0	400
SrSO4 / ksp * 100, %	0	0	0	1200
BaSO4 / ksp * 100, %	0	0	0	10000
SiO2 saturation, %	0	0	0	140
CaF2 / ksp * 100, %	0	0	0	50000
Ca3(PO4)2 saturation index	0.0	0.0	0.0	2.4
CCPP, mg/l	0.00	0.00	0.00	850
Ionic strength	0.61	0.61	1.01	
Osmotic pressure, bar	28.5	28.5	47.4	

Pass - Stage	Element no.	Feed Pressure bar	Pressure Drop bar	Conc Osmo. bar	NDP bar	Permeate Water Flow m3/h	Permeate Water Flux lmh	Beta	Permeate (Stagewise cumulative) TDS	Ca	Mg	Na	Cl
1-1	1	54.1	0.14	34.4	20.7	0.9	21.9	1.07	92.5	0	0	36.407	56.114
1-1	2	53.9	0.11	39.8	14.9	0.6	14.4	1.05	121.2	0	0	47.71	73.535
1-1	3	53.8	0.08	44.2	10.3	0.4	9	1.04	155.5	0	0	61.198	94.324
1-1	4	53.8	0.07	47.4	7	0.2	5.6	1.03	194.5	0	0	76.547	117.981

Figure A 15. Basic RO design information for 50 m^3/day permeate production for SWRO in IMSDesigns



Calculated by	Bas	Permeate flow/train	200.0 m3/d
HP Pump flow	11.90 m3/h	Raw water flow/train	285.7 m3/d
Feed pressure	5.7 bar	Permeate recovery	70.00 %
Feed temperature	31.0 °C(87.8°F)	Element age	0.0 years
Feed water pH	7.12	Flux decline %, per year	5.0
Chem dose, mg/l, 100 %	0.0 NaOH	Fouling factor	1.00
Specific energy	0.28 kwh/m3	SP increase, per year	7.0 %
Pass NDP	3.3 bar	Inter-stage pipe loss	0.207 bar
Average flux rate	24.9 lmh		
		Feed type	Brackish Well Non-Fouling

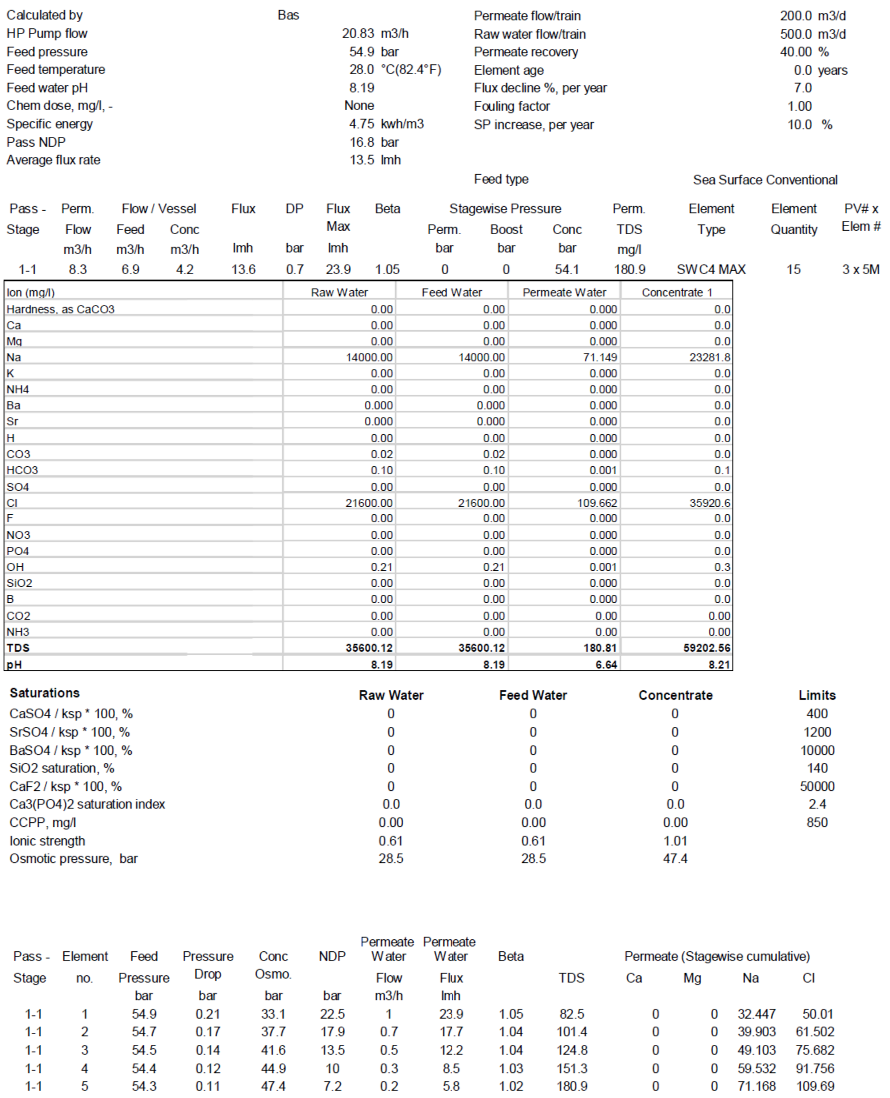
Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	7.1	2	0.8	32.1	0.6	41.6	1.19	0	0	5.1	65.5	ESPA4-LD-4040	30	6 x 5M
1-2	1.2	1.6	1.2	10.7	0.6	16.3	1.08	0	0	4.3	489.2	ESPA4-LD-4040	15	3 x 5M

Ion (mg/l)	Raw Water	Feed Water	Permeate Water	Concentrate 1	Concentrate 2
Hardness, as CaCO3	0.00	0.00	0.000	0.0	0.0
Ca	0.00	0.00	0.000	0.0	0.0
Mg	0.00	0.00	0.000	0.0	0.0
Na	600.00	600.00	49.705	1462.3	1887.8
K	0.00	0.00	0.000	0.0	0.0
NH4	0.00	0.00	0.000	0.0	0.0
Ba	0.000	0.000	0.000	0.0	0.0
Sr	0.000	0.000	0.000	0.0	0.0
H	0.00	0.00	0.001	0.0	0.0
CO3	0.00	0.00	0.000	0.0	0.0
HCO3	0.10	0.10	0.009	0.3	0.3
SO4	0.00	0.00	0.000	0.0	0.0
Cl	920.00	920.00	76.605	2241.8	2893.6
F	0.00	0.00	0.000	0.0	0.0
NO3	0.00	0.00	0.000	0.0	0.0
PO4	0.00	0.00	0.000	0.0	0.0
OH	0.00	0.00	0.000	0.0	0.0
SiO2	0.00	0.00	0.000	0.0	0.0
B	0.00	0.00	0.000	0.0	0.0
CO2	0.01	0.01	0.01	0.01	0.01
NH3	0.00	0.00	0.00	0.00	0.00
TDS	**1520.10**	**1520.11**	**126.32**	**3704.30**	**4781.71**
pH	**7.00**	**7.12**	**6.08**	**7.48**	**7.58**

Saturations	**Raw Water**	**Feed Water**	**Concentrate**	**Limits**
CaSO4 / ksp * 100, %	0	0	0	400
SrSO4 / ksp * 100, %	0	0	0	1200
BaSO4 / ksp * 100, %	0	0	0	10000
SiO2 saturation, %	0	0	0	140
CaF2 / ksp * 100, %	0	0	0	50000
Ca3(PO4)2 saturation index	0.0	0.0	0.0	2.4
CCPP, mg/l	0.00	0.00	0.00	850
Langelier saturation index	0.00	0.00	0.00	2.8
Ionic strength	0.03	0.03	0.08	
Osmotic pressure, bar	1.2	1.2	3.9	

Pass - Stage	Element no.	Feed Pressure bar	Pressure Drop bar	Conc Osmo. bar	NDP bar	Permeate Water Flow m3/h	Permeate Water Flux lmh	Beta	TDS	Permeate (Stagewise cumulative) Ca	Mg	Na	Cl
1-1	1	5.7	0.2	1.5	4.4	0.3	41.6	1.16	28.2	0	0	11.108	17.123
1-1	2	5.5	0.16	1.7	3.9	0.3	36.3	1.17	34.2	0	0	13.44	20.716
1-1	3	5.4	0.12	2.1	3.5	0.2	32.3	1.18	41.6	0	0	16.38	25.248
1-1	4	5.3	0.09	2.5	3	0.2	27.7	1.19	51.7	0	0	20.334	31.342
1-1	5	5.2	0.07	3	2.4	0.2	22.4	1.19	65.5	0	0	25.785	39.742
1-2	1	4.9	0.14	3.2	1.8	0.1	16.3	1.08	262.4	0	0	103.245	159.122
1-2	2	4.8	0.13	3.4	1.4	0.1	13.1	1.07	308.8	0	0	121.51	187.269
1-2	3	4.6	0.12	3.6	1.1	0.1	10.4	1.06	362.1	0	0	142.497	219.609
1-2	4	4.5	0.11	3.8	0.9	0.1	8	1.05	422.3	0	0	166.19	256.119
1-2	5	4.4	0.1	3.9	0.7	0	5.9	1.04	489.2	0	0	192.516	296.685

Figure A 16. Basic RO design information for 200 m^3/day permeate production for BWRO in IMSDesigns



Calculated by	Bas	Permeate flow/train	200.0 m3/d
HP Pump flow	20.83 m3/h	Raw water flow/train	500.0 m3/d
Feed pressure	54.9 bar	Permeate recovery	40.00 %
Feed temperature	28.0 °C(82.4°F)	Element age	0.0 years
Feed water pH	8.19	Flux decline %, per year	7.0
Chem dose, mg/l, -	None	Fouling factor	1.00
Specific energy	4.75 kwh/m3	SP increase, per year	10.0 %
Pass NDP	16.8 bar		
Average flux rate	13.5 lmh		
		Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	8.3	6.9	4.2	13.6	0.7	23.9	1.05	0	0	54.1	180.9	SWC4 MAX	15	3 x 5M

Ion (mg/l)	Raw Water	Feed Water	Permeate Water	Concentrate 1
Hardness, as CaCO3	0.00	0.00	0.000	0.0
Ca	0.00	0.00	0.000	0.0
Mg	0.00	0.00	0.000	0.0
Na	14000.00	14000.00	71.149	23281.8
K	0.00	0.00	0.000	0.0
NH4	0.00	0.00	0.000	0.0
Ba	0.000	0.000	0.000	0.0
Sr	0.000	0.000	0.000	0.0
H	0.00	0.00	0.000	0.0
CO3	0.02	0.02	0.000	0.0
HCO3	0.10	0.10	0.001	0.1
SO4	0.00	0.00	0.000	0.0
Cl	21600.00	21600.00	109.662	35920.6
F	0.00	0.00	0.000	0.0
NO3	0.00	0.00	0.000	0.0
PO4	0.00	0.00	0.000	0.0
OH	0.21	0.21	0.001	0.3
SiO2	0.00	0.00	0.000	0.0
B	0.00	0.00	0.000	0.0
CO2	0.00	0.00	0.00	0.00
NH3	0.00	0.00	0.00	0.00
TDS	**35600.12**	**35600.12**	**180.81**	**59202.56**
pH	**8.19**	**8.19**	**6.64**	**8.21**

Saturations	**Raw Water**	**Feed Water**	**Concentrate**	**Limits**
CaSO4 / ksp * 100, %	0	0	0	400
SrSO4 / ksp * 100, %	0	0	0	1200
BaSO4 / ksp * 100, %	0	0	0	10000
SiO2 saturation, %	0	0	0	140
CaF2 / ksp * 100, %	0	0	0	50000
Ca3(PO4)2 saturation index	0.0	0.0	0.0	2.4
CCPP, mg/l	0.00	0.00	0.00	850
Ionic strength	0.61	0.61	1.01	
Osmotic pressure, bar	28.5	28.5	47.4	

Pass - Stage	Element no.	Feed Pressure bar	Pressure Drop bar	Conc Osmo. bar	NDP bar	Permeate Water Flow m3/h	Permeate Water Flux lmh	Beta	TDS	Permeate (Stagewise cumulative) Ca	Mg	Na	Cl
1-1	1	54.9	0.21	33.1	22.5	1	23.9	1.05	82.5	0	0	32.447	50.01
1-1	2	54.7	0.17	37.7	17.9	0.7	17.7	1.04	101.4	0	0	39.903	61.502
1-1	3	54.5	0.14	41.6	13.5	0.5	12.2	1.04	124.8	0	0	49.103	75.682
1-1	4	54.4	0.12	44.9	10	0.3	8.5	1.03	151.3	0	0	59.532	91.756
1-1	5	54.3	0.11	47.4	7.2	0.2	5.8	1.02	180.9	0	0	71.168	109.69

Figure A 17. Basic RO design information for 200 m^3/day permeate production for SWRO in IMSDesigns