

Can High-Strength Reverse Osmosis Concentrate Be Accepted Into a Wastewater Treatment Plant?

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In late 2013, the City of Sunrise (city) was preparing to bring a newly constructed reverse osmosis (RO) plant online at the Springtree Utility Complex; however, industrial injection wells for disposal of RO concentrate and wastewater treatment plant (WWTP) secondary effluent were not yet constructed. To bridge the gap, the city temporarily diverted RO concentrate to the Springtree WWTP aeration basins, with secondary effluent pumped to Class I injection wells at the nearby Sawgrass WWTP.

It's common for WWTPs to discharge medium-strength nanofiltration concentrate into their activated sludge treatment processes, but a very limited number of facilities discharge higher-strength RO concentrate at significant rates comparable to the Springtree WWTP, with total dissolved solids (TDS) concentrations as high as 20,000 mg/L and flow portions as high as 8 percent.

This study evaluated the potential impacts of discharging RO concentrate to the aeration basins of the Springtree WWTP, which was completed in support of a permit application to the Florida Department of Environmental Protection (FDEP) for approval of this temporary condition. Based on the design concentrate characteristics and the predicted plant

concentrations, several potential issues of concern were evaluated, including effects on:

- ◆ Settleability
- ◆ Biological performance
- ◆ Toxicity to potential future anaerobic digestion
- ◆ Precipitation reactions
- ◆ Concrete and metal corrosion
- ◆ Potential future public access reuse

An investigation was completed to locate other facilities in Florida that specifically introduce high-strength RO concentrate to the secondary treatment process, of which only a few were identified. A literature review was completed to determine if the resulting concentrations may have an impact on the secondary treatment process. Over four years of monitoring data and observations were collected during the operation period and are also presented. The photo in Figure 1 shows the point of RO concentrate discharge to the aeration basin influent channel.

Development of Concentrate Characteristics

Design RO concentrate characteristics were developed for the design of the RO sys-

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tem at the Springtree WWTP. Because the RO well at the WWTP was an aquifer storage recovery (ASR) well prior to becoming an RO raw water production well, the water started more dilute and gradually became more brackish; therefore, conservative values of the design feed water concentrations were developed. The originally predicted design concentrate concentrations and the observed concentrate from March 2018 are presented in Table 1. It's apparent that TDS and chlorides have not reached the conservative design values assumed for the original study, but are still significant.

It was assumed that chloride, sodium, sulfate, calcium, magnesium, alkalinity, ammonia, and silica comprised the majority of the TDS and had the greatest potential impact



Figure 1. Photo of Point of Reverse Osmosis Concentrate Discharge to Aeration Basin

Table 1. Reverse Osmosis Membrane Model Input Feed, Permeate, and Concentrate Predictions

Parameter	Design Concentrate	Observed Concentrate – Mar 2018
K (mg/L)	191	-
Na (mg/L)	5,075	5,270
Mg (mg/L)	794	-
Ca (mg/L)	873	-
Ba (mg/L)	0.2	0.04
NO ₃ (mg/L)	0	0.08
NH ₄ (mg/L)	0	-
Cl (mg/L)	9,794	7,420
SO ₄ (mg/L)	2,556	2330
SiO ₂ (mg/L)	104	-
TDS (mg/L)	19,790	15,800
pH	6.67	6.9

Table 2. Design Versus Observed Wastewater Treatment Plant Influent Concentrations

Parameter	Design Min Daily Flow + RO Flow	Observed Min Daily Flow + RO Flow	Maximum Observed Chlorides
Na (mg/L)	448	447	-
Mg (mg/L)	70	-	-
Ca (mg/L)	107	-	-
Ba (mg/L)	0	0	-
NO ₃ (mg/L)	0	0	-
NH ₄ (mg/L)	21	-	-
Cl (mg/L)	883	629	1,040
SO ₄ (mg/L)	308	197	-
SiO ₂ (mg/L)	5	-	-
TDS (mg/L)	1,906	1,339	-

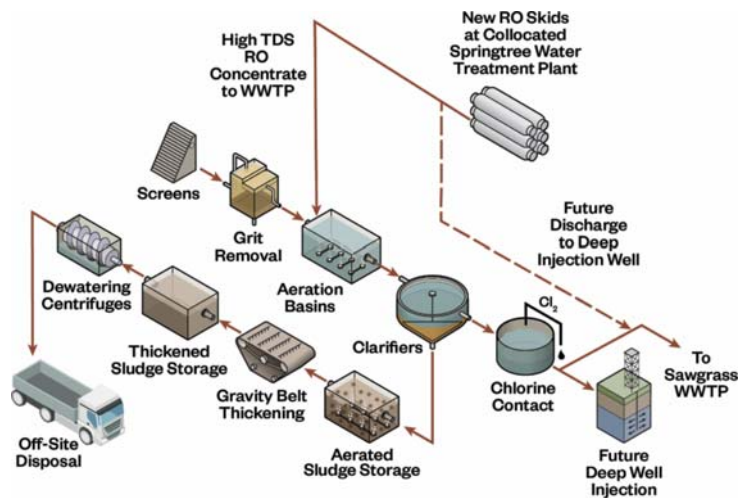


Figure 2. Process Flow Diagram of the Springtree Wastewater Treatment Plant

on operations at the Springtree WWTP; therefore, the development of concentrate characteristics and subsequent analysis were limited to these constituents. Other components, such as iron, nitrate, phosphorus, and biological or chemical oxygen demands were expected to be at low levels (typical of the Floridan aquifer) and were not expected to have an impact on plant operation. Data were unavailable for other potential constituents including bromide, radium, radon, arsenic, hydrogen sulfide, and heavy metals.

Plant Impact Evaluation

The plant impact evaluation prior to operation was based on the Springtree WWTP minimum and average daily flow (ADF) for the year 2013 of approximately 5.4 and 8.5 mil gal per day (mgd), respectively. Addition of a RO concentrate stream of 0.5 mgd with the minimum daily flow was examined as the worst-case scenario representing the lowest dilution scenario. From 2013 to 2018, concentrate flows have frequently reached approximately 0.5 mgd and the ADF is approximately 8.1 mgd. The concentrations of constituents of concern for the design values used for the original evaluation, compared to actual observed values, can be found in Table 2.

A literature review was completed in order to predict if the resulting concentrations may have an impact on the secondary treatment process; potential impacts to plant infrastructure were also considered. Potential effects of adding RO concentrate to the Springtree WWTP that were investigated include:

- ◆ Settleability
- ◆ Biological performance
- ◆ Toxicity to potential future anaerobic digestion
- ◆ Precipitation reactions
- ◆ Concrete and metal corrosion
- ◆ Effects on potential future public access reuse

Figure 2 shows the process flow diagram of the Springtree WWTP and the point of RO concentrate discharge into the process.

Settleability

Several studies have reported that settleability may be affected by high monovalent ion, sodium, or sodium chloride concentration. The exchange of divalent cations for monovalent cations (i.e., Na⁺, K⁺) in the floc may affect settling of the floc by weakening biopolymer bonds and causing the release of soluble proteins. This phenomenon may also affect the dewaterability of the waste activated sludge (WAS). This effect was not observed in an appreciable amount when the sodium-to-divalent cation ratio was less than 2 on an equivalent basis (Higgins and Novak, 1997). After dilution with the minimum day flow, the sodium-to-divalent cation ratio at the Springtree WWTP was expected to be approximately 1.8.

In addition, bench-scale studies have shown that the effluent total suspended solids (TSS) concentration increased when sodium concentrations were approximately 500 to 1,100 mg/L (Novak et al., 1998). The worst-case minimum day flow sodium concentration in this analysis was predicted to be 448 mg/L and minimum hour concentrations

may be as high as 892 mg/L; therefore, it was recommended that the secondary effluent TSS be monitored for signs of plant upset, and if the treatment performance is affected, the RO skid could be shut down during low flows at night.

In addition, the WasteReuse Foundation (2008) reported that settleability changes from sodium chloride (NaCl) are not expected for concentrations less than 5,000 mg/L. Based on the predicted sodium concentration in the concentrate, the calculated NaCl concentration in the plant flow should not exceed 1,120 and 2,270 mg/L during a minimum day flow and minimum hour flow, respectively.

Effects on Biological Process

Typically, only very high chloride concentrations would cause biological inhibition; for example, chloride concentrations greater than 8,000 mg/L would typically inhibit nitrification (WasteReuse Foundation, 2008) and reduction in biochemical oxygen demand (BOD) degradation is not expected below 5,000 mg/L (WasteReuse Foundation, 2008). One study showed, however, a 25 percent reduction in nitrification rate at a NaCl concentration of 3,000 mg/L in a batch assay (Campos et al., 2002). Based on the predicted sodium concentration in the concentrate, the NaCl concentration in the plant flow should not exceed 1,120 and 2,270 mg/L during a minimum day flow and minimum hour flow, respectively. It was not expected that the NaCl concentration would reduce nitrification significantly, but it was recommended that the aeration basins should be monitored for signs of toxicity.

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Auxiliary discharge flows from the Springtree WWTP will be intermittent. The system design allows for the ability to neutralize cleaning solutions in the clean-in-place tanks by introducing any chemicals that may be required from the sodium hydroxide feed system or the clean-in-place batch tank. Instrumentation is provided to monitor pH. Once pumped to the scavenger system, there exists the ability to recirculate flows from either tank for purposes of mixing or further neutralization with other waste flows. Flow will be pumped from the scavenger tank and may include floor washdown water, a mixture of spent sodium hydroxide and sodium hypochlorite solution from the odor control system at a pH less than 9.5, and cleaning system waste. The pH will range from 2 to 11. Cleaning is anticipated to be performed every three to six months. The plant staff will have the ability to schedule cleans based on monitoring the train performance, so taking the system offline for cleaning will be a planned activity. Based on this, it's not expected that the auxiliary flows will have a significant effect on the Springtree WWTP process or effluent water quality.

Toxicity to Anaerobic Digestion

The Springtree WWTP was projected to possibly implement anaerobic digestion during the ongoing discharge of RO concentrate to the secondary treatment process. Sodium inhibition of anaerobic digestion is a possible effect of concentrate addition. It's recommended by the WaterReuse Foundation (2008) that the sodium concentration be below 2,000 mg/L if anaerobic digestion is to be utilized; the pre-

dicted concentration is from 301 to 448 mg/L. Feijoo et al. (1995) found a 25 percent reduction in methane production, with a sodium concentration of 1,500 mg/L. Toxicity to anaerobic digestion is possible and should be considered if conversion to anaerobic digestion is planned for the future. Metals are also possible concentrate constituents that have the potential to inhibit anaerobic digestion and could partition into the biosolids and inhibit anaerobic digestion. Metals data for the raw source water were unavailable at the time of the analysis, so it was not possible to evaluate potential metal toxicity to anaerobic digestion.

Precipitation Potential

Precipitation of calcium carbonate or other compounds may increase the solids generated within the facility. The membrane manufacturer's model predicted that the concentrate will contain barium sulfate (BaSO₄) and strontium sulfate (SrSO₄) above saturation in the concentrate; after dilution, BaSO₄ and SrSO₄ were predicted to be below saturations levels. Also, calcium sulfate (CaSO₄) and silicon dioxide (SiO₂) were not predicted to be above saturation, but are present at 63 and 46 percent of saturation, respectively, and may precipitate if concentrations vary. The conditions indicate that precipitation may occur prior to mixing with the wastewater flow. It was recommended that the concentrate pipeline pressure be monitored for signs of clogging with precipitate.

An uncalibrated BioWin™ model of the Springtree WWTP had previously been developed and was used as another tool to determine predicted impacts the RO concentrate may have on the potential for precipitation of

particular solids in the wastewater treatment process. BioWin has the capability of modeling ferric phosphate, ferric hydroxide, struvite (ammonium magnesium phosphate), hydroxy-dicalcium-phosphate (HDP), hydroxy-apatite (HAP), and calcium carbonate. The model results indicate the potential for precipitation of calcium carbonate. In addition, if anaerobic digestion is implemented at the WWTP, the model indicated that the struvite precipitation potential is significant.

The Langelier Saturation Index (LSI) is a measure of scaling potential. The LSI values greater than 0 indicate the scaling potential and the values greater than 0.5 tend to exhibit noticeably increased scale-forming properties. The LSI is calculated to be 0.45 for the concentrate. After mixing with the wastewater flow, the LSI is slightly negative, which indicates that scaling is not likely.

The Stiff & Davis Stability Index (S&DSI) is typically used for high TDS solutions (>10,000 parts per mil [ppm]) and is also used as a measure of scaling potential. Negative values indicate low scaling potential. The S&DSI is calculated to be -0.32 for the concentrate.

Although the BioWin model indicates the potential for calcium carbonate precipitation, the S&DSI, which is used for high TDS solutions, indicates that precipitation in the concentrate is unlikely. Also, the LSI, after mixing, indicated low potential for scaling. Based on these results, it was recommended that the point of introduction of the concentrate be monitored for scale buildup, and that potential fouling of ceramic fine bubble by precipitation be monitored by measuring increases in the blower discharge pressure.

Structural and Corrosion Concerns

In addition to the potential effects on the biological processes within the plant, other impacts to the plant infrastructure are possible, including corrosion of concrete and metal due to sulfates, sulfide, or chloride. Concentrate from RO treatment of groundwater may include hydrogen sulfide, which may increase corrosion of concrete and other WWTP components. No data were provided on the hydrogen sulfide concentration in the raw water.

High levels of sulfate typically are present in the RO concentrate. Although not a major toxicity concern, sulfate could increase concrete corrosion by either direct or indirect attack. The direct attack occurs when sulfates react with free calcium hydroxide in concrete to form calcium sulfate, and then with hydrated calcium aluminates to form calcium sulfoaluminate. These compounds cause concrete to soften. The American Concrete Insti-

Table 3. Projected Reclaimed Water Effluent and Water Quality Standard

Constituent (mg/L)	FDEP Limit Monitoring Well	Current ADF + RO Flow
TDS	500	1,336
Sodium	160	301
Chloride	250	599
Sulfate	250	236
Iron	0.3	0.41

Table 4. U.S. Environmental Protection Agency
Irrigation Recommendations

Constituent (mg/L)	EPA Recommended Limits	Current ADF + RO Flow Concentration
TDS	500-2,000	1,336
Fluoride	1-15	0.20
Iron	5-20	0.41

tute reports the following levels of corrosion potential with sulfate levels:

- ◆ SO_4^{2-} (mg/L) < 150 mg/L – negligible corrosion
- ◆ 150 mg/L < SO_4^{2-} (mg/L) < 1,500 mg/L – moderate corrosion
- ◆ 1,500 mg/L < SO_4^{2-} (mg/L) < 10,000 mg/L – severe corrosion
- ◆ SO_4^{2-} (mg/L) > 10,000 mg/L – very severe corrosion

The RO concentrate addition to the WWTP could result in a sulfate concentration from 238-308 mg/L after mixing with wastewater, which would result in a moderate risk of corrosion under direct sulfate attack; under indirect attack, sulfate could be converted to sulfide under anaerobic conditions. Proper mixing and low detention time in the aeration basin influent channel will help to prevent conditions where sulfate may undergo conversion to hydrogen sulfide. Increased sulfate concentrations during minimum hour low-flow periods are not expected to significantly impact corrosion, but it was recommended that the concrete surfaces in the influent channel and airbays be periodically inspected.

In addition, chloride concentrations greater than 1,000 mg/L could cause concrete deterioration and corrode metal surfaces. The chloride concentration should not exceed 883 mg/L in the plant flow during minimum day flow. Higher chloride concentrations during minimum hour low-flow periods are not expected to significantly impact corrosion, but it was recommended that the metal surfaces of nearby gates and equipment should be periodically inspected.

Reuse Impact

Although the Springtree WWTP does not currently distribute reuse water and is planning to dispose of its treated effluent and commingled RO concentrate to the new deep injection wells, the city's 2008 master plan identified potential opportunities for public access reuse of the WWTP effluent. Potential monitoring well limits for sites where public access reuse is applied that may be impacted by RO concentrate addition are listed in Table 3; also listed are the average predicted effluent concentrations.

The predicted reclaimed water concentrations are greater than the monitoring well limits for all parameters listed. Depending on the groundwater conditions, there may not be enough dilution of the high TDS and high-chloride reclaimed water with ambient groundwater to meet the monitoring well limits. Groundwater modeling would be required to determine if sufficient dilution is possible to avoid violation

Table 5. Water Quality Goals for Bermuda Grass (Burden et al., 2010)

Parameter	Bermuda Grass Acceptable Water Quality Range	Current ADF + RO Flow Concentration
Calcium (mg/L)	40 - 120	82.6
Magnesium (mg/L)	6 - 20	46.4
Potassium (mg/L)	0.5 - 10	Not calculated
Sodium (mg/L)	0 - 50	301
Iron (mg/L)	2 - 5	0.41
Alkalinity (mg/L)	0 - 100	250
Chloride (mg/L)	177 - 355	599
Sulfate (mg/L)	0 - 414	236
TDS (mg/L)	1,000 - 1,500	1,336
Boron (mg/L)	0.2 - 0.8	Not calculated

Table 6. Summary of Facilities in Florida With High Total Dissolved Solids and Mixed Liquor Suspended Solids

WWTP	RO Flow ADF (mgd)	Avg. RO TDS (mg/L)	Avg. Inf Flow (mgd)	Secondary Process TDS (mg/L)	Secondary Process Cl- (mg/L)	Time Period	Comments
Anastasia Island WWTF	0.5	10,000	2.8	2,100	700	2007 to Current	RO concentrate treatment through plant permitted by FDEP
North Port WWTP	0.1	14,800	1.9	1,500	410	Feb to Apr 2013	Short term emergency operation
Hollywood SRWWTP	-	-	45	2,800	1,500	Continual	High TDS and chlorides related to coastal I/I
Key West WWTP	-	-	6.5	-	7,070 to 11,460	1989-1991	Plant performed well for TSS, BOD ₅ , and TN removal (although BNR not required), but avg. SVI = 172 ml/g, clarifier SOR = 342 gal/ft ² day
Miami-Dade NDWWTP "High Cl-" Train	-	-	-	-	2,400	2003-2005	HPO plant with RAS chlorination, avg. SVI = 132 ml/g
Miami-Dade CDWWTP	-	-	-	-	1,050	2003-2005	HPO Plant with RAS chlorination
Proposed Springtree WWTP	0.5	15,800	5.4	1,340	630 (max observed 1,140)	2013 - 2018	Design RO concentrate and minimum day flow

of the reuse limits at the sampling point.

Vegetation concerns may result from salinity, as well as other constituents, which adversely affect the growth of plants and/or grasses. The U.S. Environmental Protection Agency (EPA) Guidelines for Water Reuse (2004) gives recommended limits for various constituents in reclaimed water used for irrigation. Table 4 provides the recommendations for the constituents that were predicted in the RO concentrate.

The TDS concentrations above 2,000 mg/L could only be tolerated by salt-tolerant plants on sandy and well-drained soils, and the WateReuse Association also reported that grasses and citrus trees cannot grow with TDS

concentrations greater than 1,000 mg/L. Weinberg (2004) reported that TDS in the range of 1,100 to 2,200 mg/L may have growth effects on sensitive plants, but the effect is reduced by leaching. Sandy soils are typical in the region of the Springtree WWTP, but due to the variability in the literature, it is not possible to determine if the high level of TDS may present toxicity issues for irrigated plants and grasses; no irrigation issues are expected for iron or fluoride. The EPA also gives recommended limits for aluminum, arsenic, beryllium, boron, cadmium, chromium, cobalt, copper, lead, lithium, manganese, molybdenum,

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nickel, selenium, vanadium, and zinc, but the data are not available to compare these constituents to the EPA recommendations.

Bermuda grass is a common vegetation type in the service area and is also a sensitive receptor for constituents that would be found in the reclaimed water with constituents from RO concentrate. The water quality goals for Bermuda grass and the average case concentrations for equalized flow rate (8.5 mgd + 0.5 mgd concentrate) can be found in Table 5.

The predicted magnesium, sodium, alkalinity, chloride, and TDS exceeded the Bermuda grass acceptable range. Because of the sandy soils and annual heavy rainfall in the area (65 in./year) the higher magnesium and alkalinity are not of concern. The high-predicted sodium and chloride concentrations may be detrimental to turfgrass. The TDS concentration is 45 percent higher than the high end of the reported range. Kaffka (2001) reported, however, no yield

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loss in Bermuda grass for a TDS concentration as high as 3,800 mg/L. Karleskint, et al. (2011) also observed no significant difference between grasses irrigated with potable water versus those irrigated with reclaimed water, with a TDS of approximately 1,900 mg/L.

Other Facilities Receiving Reverse Osmosis Concentrate

It's more common for facilities to receive nanofiltration concentrate, rather than RO concentrate. A limited number of facilities discharge RO concentrate into wastewater treatment plants. An investigation was completed to locate other facilities in Florida that specifically introduce RO concentrate to the sec-

ondary treatment process. In addition, wastewater treatment facilities for coastal communities that experience inflow and infiltration of salt water into the wastewater collection system can experience high background chlorides and TDS. In general, none of these facilities reported major treatment issues related to high chlorides and TDS. Table 6 provides a summary of the facilities investigated and compares them to the proposed application at the Springtree WWTP.

Four Years of Operation at Springtree Wastewater Treatment Plant

Discharge of concentrate to the Springtree WWTP aeration basins was initiated in October 2013 and has continued through 2018. The facility has operated with no reported issues related to concentrate addition. Daily monitoring data available for chlorides, sludge volume index (SVI), and effluent TSS show no apparent negative effects on operation due to concentrate addition, as demonstrated by Figures 3 and 4. Also of note, the RO concentrate is generally turned off on the weekends, and on Mondays, turned back on. The process generally shows no issues acclimating to the on/off discharge of concentrate into the aeration basins. Anecdotally, operators report beneficial effects of concentrate on the process. In addition to a small increase in settleability and SVI, microscopic analysis reveals healthier microbiological indicators during times of concentrate addition, with a higher occurrence of stalked ciliate communities.

Summary and Conclusions

Discharge of concentrate to the Springtree WWTP aeration basins was initiated in October

2013 and has continued through 2018. The facility has operated with no reported issues related to concentrate addition. The predicted effluent concentrations of various parameters affected by concentrate addition versus levels of concern are summarized in Table 7. The following issues of potential concern were evaluated:

Settleability

Although reduction in dewaterability was not anticipated based on predicted and observed concentrations, the predicted minimum day flow sodium concentration exceeded recommended values for affecting settleability. After four years of operation, however, settleability remains excellent, with SVI rarely exceeding 100 g/ml, and effluent TSS and carbonaceous biochemical oxygen demand (CBOD₅) permit requirements have been consistently met.

Effect on Biological Process

Nitrification was not affected by addition of RO concentrate. In addition, plant staff also reported no effects from intermittent discharge of RO system cleaning solutions performed every three to six months. Plant staff also reported anecdotal evidence that the addition of RO concentrate actually helps the process and promotes healthy microbiological populations.

Toxicity to Anaerobic Digestion

Although a cursory analysis showed no concern at predicted concentrations, toxicity to anaerobic digestion is possible and should be considered further if conversion to anaerobic digestion is planned for the future.

Precipitation Potential

The BioWin model, S&DSI, and LSI indi-

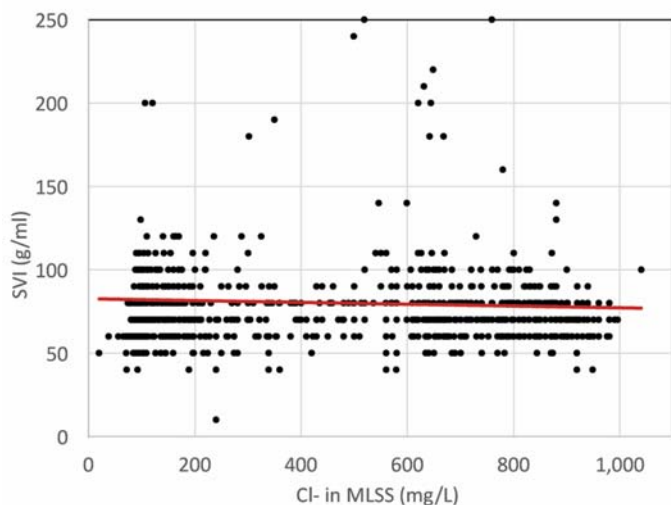


Figure 3. Chloride Concentration Versus Sludge Volume Index (2015 - 2017)

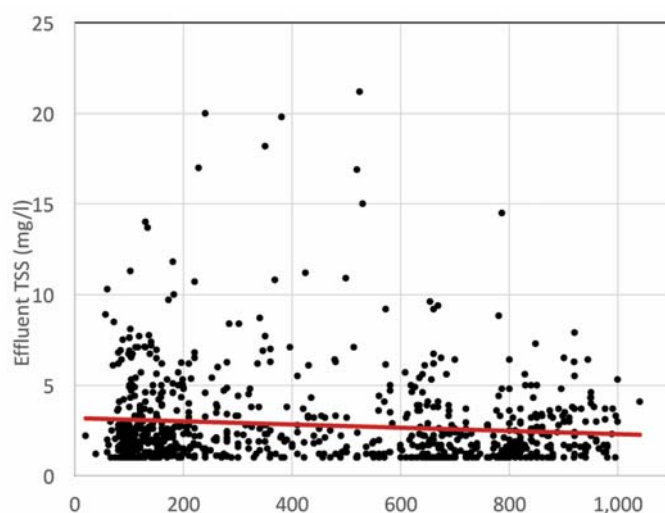


Figure 4. Chloride Concentration Versus Effluent Total Suspended Solids (2015 - 2017)

Table 7. Springtree Wastewater Treatment Plant Design Effluent Concentrations Versus Levels of Concern

Parameter (mg/l)	Min Day Flow Design Concentration	Plant Biological Performance	Concrete and Metal Corrosion	Reuse Monitoring Well Limit	Bermuda Grass/EPA Irrigation Recommendations	Comments / Observations
Na	448	500-1,100 (SVI), 1,500 (digestion)		160	0-50	No reduction of SVI observed
Mg	70				6-20	Not significant concern in well drained FL soils. Concern related to struvite potential for future anaerobic digestion.
Ca	107				40-120	Calcium carbonate precipitation possible at discharge point
NO ₃	0.003			10		Insignificant
Cl	883	8,000 (nitrification)	1,000	250	177-355	Biological process toxicity negligible, no concrete or metal corrosion observed
F	0.30				1-15 (EPA)	Insignificant
SO ₄	308		150 - 1,500	250	0-414	No concrete or metal corrosion observed
TDS	1,906			500	1,000-1,500, 500-2,000 (EPA)	May present problems in reuse sampling wells
Fe	0.41			0.3	2-5, 5-20 (EPA)	Not a significant concern
Alkalinity (as CaCO ₃)	250				0-100	Not significant concern in well drained FL soils
NaCl	1,112	3,000 (nitrification) 5,000 (SVI / BOD)				Biological process toxicity likely negligible, no effects on nitrification or settleability observed

cated low potential for scaling. No evidence of scaling was observed at the point of introduction of concentrate and no signs of accelerated fouling of ceramic fine bubble diffusers were reported.

Structural and Corrosion Concerns

The RO concentrate addition to the WWTP could result in a sulfate concentration indicative of a moderate risk of corrosion. It was recommended that the concrete surfaces in the influent channel and airbays, and metal surfaces of nearby gates and equipment, be periodically inspected. No structural or corrosion concerns were observed or reported on concrete surfaces in the influent channel, or airbays or metal surfaces of nearby gates and equipment, after four years in operation.

Reuse Impact

At the concentrations anticipated, there is moderate concern for land application of reuse water; however, there are multiple examples of reuse being successfully applied with TDS and chloride concentrations higher than that predicted at the Springtree WWTP.

Other Facilities Receiving Reverse Osmosis Concentrate

An investigation was completed to locate other facilities in Florida that specifically introduce RO concentrate to the secondary treat-

ment process. In addition, wastewater treatment facilities for coastal communities that experience inflow and infiltration of salt water into the wastewater collection system can experience high background chlorides and TDS. In general, none of these facilities reported major treatment issues related to high chlorides and TDS.

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