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Effect of feed water characterization changes on brackish-water reverse osmosis plant operation: the town of Jupiter, Florida

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ABSTRACT

The feed water supply for brackish-water reverse osmosis (BWRO) water treatment facilities is commonly obtained from groundwater sources. During pumping, the production aquifer is generally recharged by the underlying aquifer at many facilities. Higher salinity water occurring below the production aquifer leaks upwards, which commonly causes the production aquifer salinity to increase over time. The pumping rate, wellfield design, the transmissivity of the aquifer, the leakance value of the confining unit, and the water quality in the underlying aquifer affect the rate of change in water quality. The Town of Jupiter Reverse Osmosis facility pumps feed water from the upper part of the Floridan Aquifer System. The permitted treatment capacity is 62,281 m^3/d for the reverse osmosis design process, which requires about 77,851 m^3/d of feed water. Consistent with the standard conceptual model of upwards recharge from the underlying aquifer when pumping, analysis of the water quality changes in the production wells indicate that the dissolved chloride concentration in most of the wells is increasing over time. Historically, the dissolved chloride concentration of the feed water has increased by an average of 314 mg/L (605 mg/L TDS) from 2014 to 2019. The average projected dissolved chloride value at the 20-y point is 1,268 mg/L (2,439 mg/L TDS) from 2019 to 2039. Analysis of the dissolved chloride concentration changes in the BWRO production wells indicates that the facility can continue to meet the potable supply water demand over the next 20 y. The BWRO plant was initially designed to treat raw water with a dissolved chloride concentration of up to 2,955 mg/L (5,683 mg/L of TDS). The town has plans to modify the plant process and equipment to allow treatment of feed water up to a concentration of 11,500 ppm TDS (5,980 mg/L of dissolved chloride), which should allow it to sustainably accommodate future water demand as salinity increases in the upper Floridan aquifer raw water supply. The Town of Jupiter BWRO facility provides an example of a successful facility design, operation, and continued planning to adjust for anticipated changes in the feed water quality of a BWRO facility.

Keywords: Brackish-water reverse osmosis desalination; Groundwater quality; Aquifer characteristics; Feed water quality salinity change; Town of Jupiter, Florida

1. Introduction

The Town of Jupiter (TOJ) services a 234,718 km^2 area or about one-tenth of Palm Beach County, Florida [1]. The water system was purchased from Tri-Southern Utilities in 1978, when it could produce 9,464 m^3/d of drinking water using freshwater pumped from the Surficial Aquifer System and treated using the lime-softening process. Three water treatment plants are operated by the TOJ, including a nanofiltration and ion exchange plant (replacement for

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the lime-softening plant) treating water from the Surficial Aquifer System, and a brackish-water reverse osmosis (BWRO) desalination plant treating water from the upper part of the Floridan Aquifer System. The nanofiltration and ion exchange plants have capacities of 65,918 and 8,183 m^3/d respectively. Formally commissioned in 1990, the BWRO facility has been expanded three times and currently has a capacity of 62,281 m^3/d. A 111,670 m^3 water storage component and backup power generator ensure reliable treated water supply during most emergencies.

The TOJ was one of the first large communities to utilize membrane water treatment technologies in the United States. Based on the high probability of pumping-induced saltwater intrusion into the freshwater aquifer from the adjacent Atlantic Ocean, the town initiated sustainable management practices by limiting the use of the Surficial Aquifer System, which contains freshwater. The BWRO facility and corresponding upper Floridan Aquifer System water source are critical components towards supplying 62,281 m^3/d or about 75% of the total water demand during times of drought [2]. The potable water service area includes the TOJ, the Town of Juno Beach, and some unincorporated areas of Palm Beach and Martin Counties [1]. The TOJ water treatment plant (WTP) is shown in Fig. 1, along with the Central Boulevard High Service Pump Station and Juno Repump Station.

National, regional, and local investigations have indicated the need to predict and plan for impacts to water supply from natural disasters and climate change [3]. To prevent undesirable changes in the water quality within freshwater aquifers used exclusively in the past for water supply, the expanded use of brackish groundwater from the Floridan Aquifer System requires careful planning [4]. The TOJ is an award-winning leader in developing planning tools and identifying achievable and cost-effective goals to mitigate perceived and real impacts to their water supply [2,5].

Dramatic change to the water quality of brackish-water sources is problematic to the design and longevity of a BWRO treatment facility [6]. If the feed water source of a BWRO plant is characterized by extreme salinity fluctuations, it is challenging to design the desalination process and even more difficult to economically operate a BWRO plant for the duration of the intended design lifespan [7]. For the plant to properly operate for the entire life expectancy, a BWRO facility process design must be adequately robust to accommodate the expected variations in the feed water quality [8]. The initial water quality and anticipated stability of the feed water supply are critical

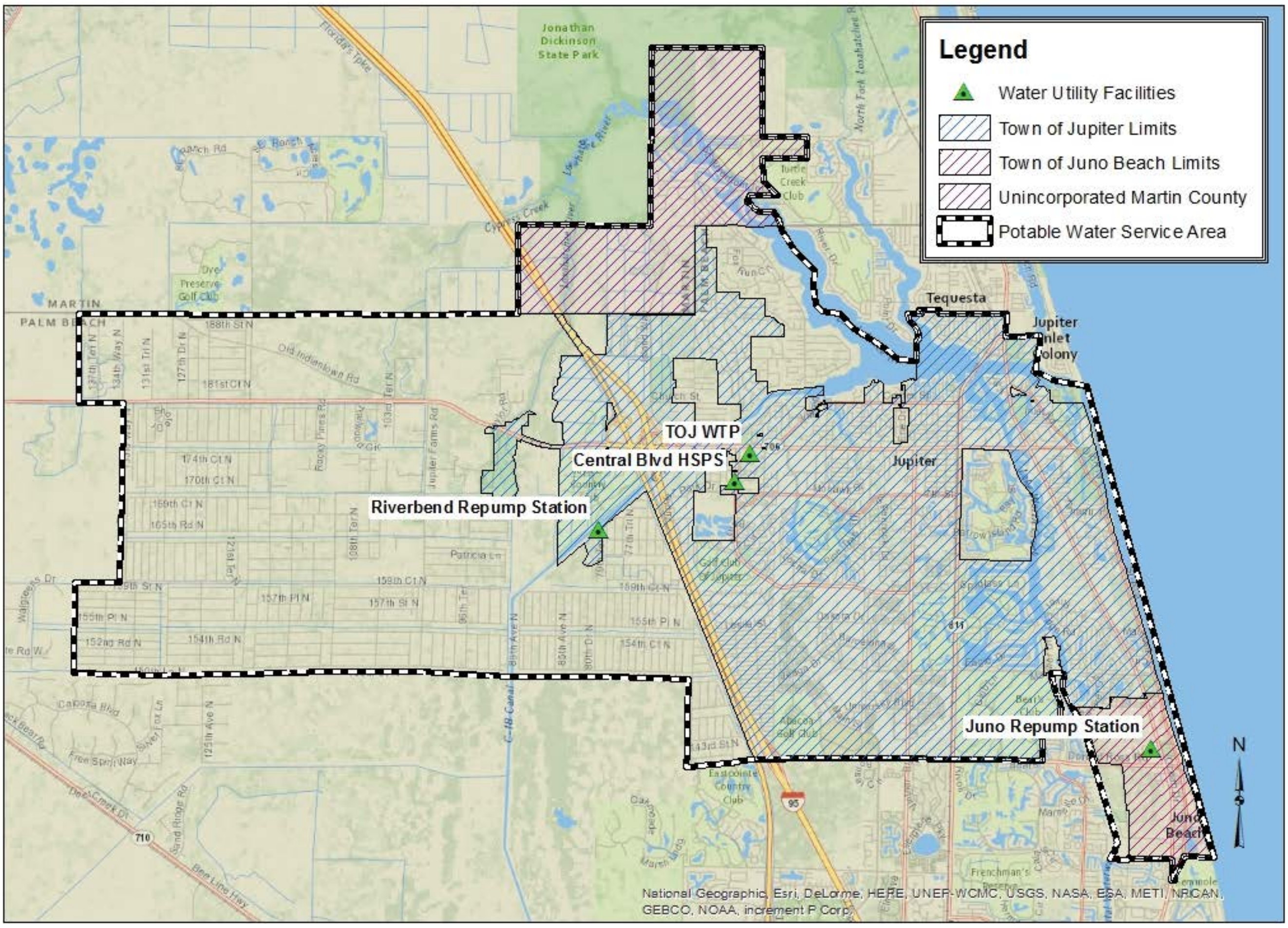

Fig. 1. Town of Jupiter Water service area [1].

components when considering the process design of all BWRO desalination treatment facilities [9].

Hydrogeologic investigations are often conducted to characterize the stability of the feed water supply [10]. A conceptual model of the aquifer or aquifer system is developed [11] and utilized as the framework to support solute transport modeling for predicting the future aquifer water quality changes [12]. Various scenarios are modeled to estimate the performance of the investigated aquifer or aquifer system and to guide the process design of the BWRO facility. This systematic approach is generally successful, but the resultant model findings and recommendations have an inherent error range or could have utilized an incorrect conceptual model, which can misrepresent the projected water quality changes when projected 20 to 40 y into the future [13].

The purpose of this research is to assess the long-term water quality changes of the TOJ BWRO facility to ascertain if design or operation modifications are expected to be needed before the anticipated 30-y design life span is achieved.

2. Materials and methods

2.1. Allowable aquifer withdraws

A South Florida Water Management District (SFWMD) Consumptive Use Permit allows the TOJ to withdraw water from the Surficial and Floridan Aquifer Systems. The total annual allocation is 18.8 million m^3 from the upper part of the Floridan Aquifer System and 30.2 million m^3 from the Surficial Aquifer System. The maximum monthly allocation from the upper Floridan aquifer is 2.5 million m^3 and 2.7 million m^3 from the surficial aquifer. The combined total annual allocation cannot exceed 39.2 million m^3, and the combined maximum monthly allocations cannot exceed 4.1 million m^3 [14].

2.2. Description of the BWRO facility

A Florida Department of Environmental Protection (FDEP) permit authorizes the TOJ water treatment facility operation, which includes the three separate processes of reverse osmosis (RO), ion exchange, and nanofiltration (NF). The permitted treatment capacity is 62,281 m^3/d for the RO process, 8,183 m^3/d for the ion exchange process, and 65,918 m^3/d for the NF process [16]. The South Florida Water Management District (SFWMD) permits a daily withdrawal allocation of 81,375 m^3/d from the upper Floridian aquifer, which allows the RO plant to produce 62,281 m^3/d of finished water supply at a 75% recovery rate [1,16]. The ion exchange plant, constructed in 1999, utilizes Surficial aquifer raw water to produce permeate water of low color and increased alkalinity, which is then blended with the RO permeate waters to enhance the esthetic and chemical qualities of the total blended finish water. The NF plant was constructed in 2010 and utilizes raw water from the Surficial Aquifer System. The entire water treatment process facility produces 113,562 m^3/d of potable water to service more than 80,000 people within the TOJ, Juno Beach, and unincorporated areas of Palm Beach and Martin Counties [15].

2.3. Analysis of pumpage, water quality, and relative data

Data were obtained from the TOJ utility operating staff who report monthly pumping rates and water quality information required by the SFWMD permit conditions. Well and water treatment plant locations in Palm Beach County, Florida, were obtained from the water use permit and the 10-y water supply facilities plan (Fig. 2) [1,15]. The BWRO process design was obtained from the TOJ water utilities information brochure [15]. A series of reports were used to obtain the hydrogeologic characteristics of the upper part of the Floridan Aquifer System [1,15–20].

The ratios between major ions in brackish water are related to the known ratio between the major ions in seawater. However, brackish groundwater ratios differ due to rock and water interactions. An estimate of TDS concentration from dissolved chloride data can be made by dividing the dissolved chloride concentration by 0.55 [13]. For this research, a division of 0.52 was utilized, which is anticipated to represent the relationship of dissolved chloride concentration more appropriately to TDS for the Lower Hawthorn/Suwannee Zone I aquifer on the Florida West coast, which is the upper part of the Florida Aquifer System in that area [10].

Dissolved chloride measurement data were plotted vs. time to analyze the linear regression of the data. The relationship between dissolved chlorides and the cumulative monthly pumpage can often be linear [6,10,13]. For each well, a trendline of the dissolved chloride concentration change over time was obtained, as well as the associated equation and an R^2 value. The p-values were also calculated to assess the statistical significance of the regression line fit to the data. The historical trending water quality changes were then projected over 40 y to gain insight into the question concerning whether the plant design, operation, and equipment will require modification before the design life expectancy is concluded.

3. Background

3.1. Wellfield description and hydrogeology

The TOJ Floridan aquifer wellfield was initially constructed in the 1990s. The utility department has monitored water quality trends and adjusted production operations to minimize withdrawal impacts since inception [1]. The salinity of the upper Floridan aquifer raw water supply is expected to increase over time with use [20]. The rate of salinity increase can be controlled or slowed down in most cases by managing the rotation and pumping rates of the wells in service [21]. The TOJ has generally equalized pumping from each of the upper Floridan aquifer production wells since 2004, which has slowed the water quality degradation [1]. Additional upper Floridan aquifer wells have been added over time to mitigate over-pumping of individual wells and to reduce the rate of salinity increase [22]. Table 1 provides the construction details for the production wells that supply feed water to the BWRO facility. The well casing depth in the lower part of the Floridan Aquifer System was based on the depth at which a significant quantity of water could be pumped from each well [17]. To meet the finished

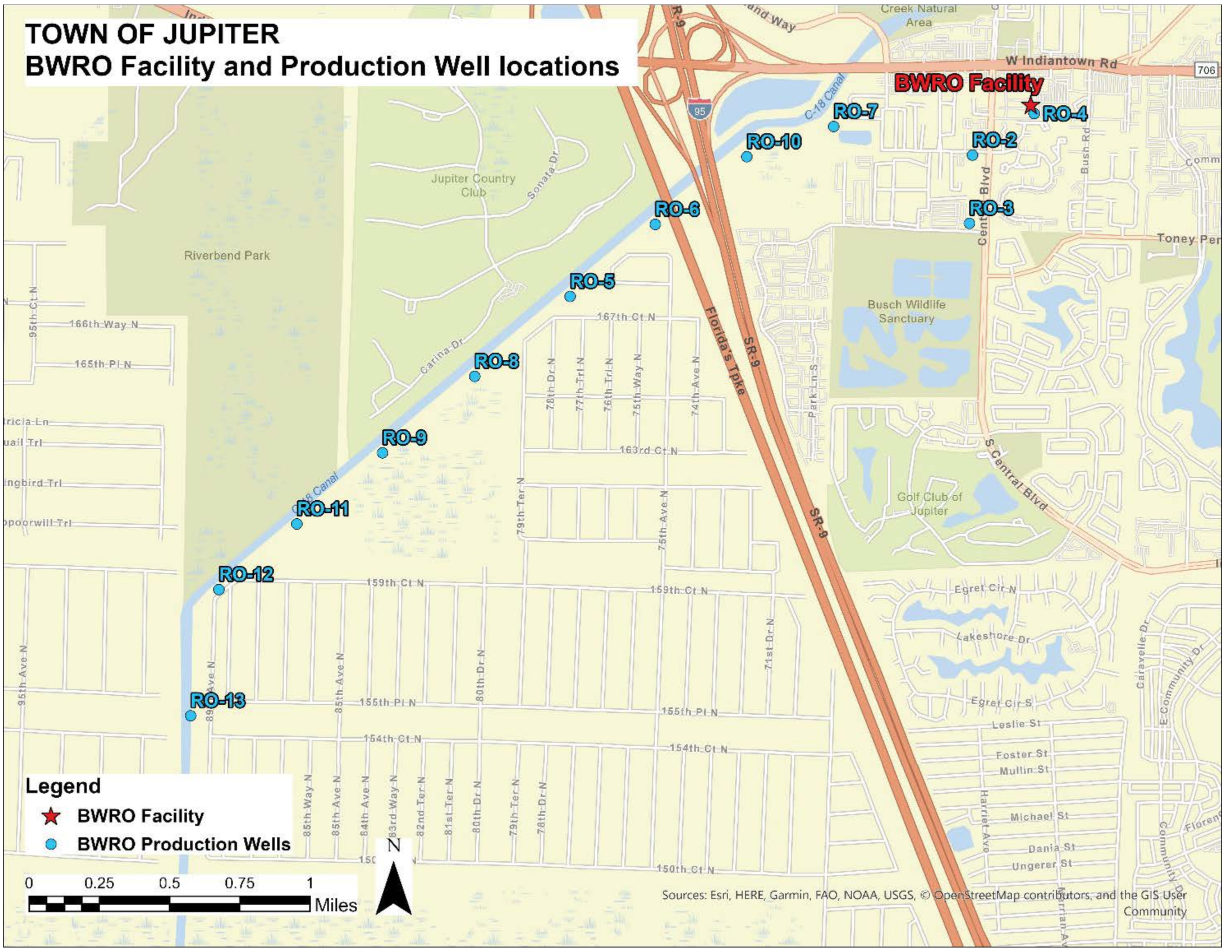

Fig. 2. Identification numbers and locations of the Town of Jupiter BWRO plant production wells [16].

Table 1
Town of Jupiter production wells construction details [14]

Well number	Total depth (m, bls)	Casing depth (m, bls)	Well diameter (cm)
RO-2	509.9	314.5	40.6
RO-3	492.2	310.0	40.6
RO-4	418.5	324.6	40.6
RO-5	507.5	442.2	40.6
RO-6	505.9	446.5	40.6
RO-7	506.6	405.4	40.6
RO-8	469.4	394.7	40.6
RO-9	463.3	376.4	40.6
RO-10	492.8	373.1	40.6
RO-11	457.2	320.0	40.6
RO-12	457.2	320.0	40.6
RO-13	320.0	320.0	40.6

potable water supply demand, the TOJ also monitors and makes incremental modifications to the BWRO design process and equipment when total dissolved solids (TDS) are observed to fluctuate [1].

The generalized geology and hydrogeology are given in Fig. 3 and the site-specific lithology is given in Fig. 4. Note that this graphic was obtained from a study of the hydrogeology in the Floridan Aquifer System for Martin and St. Lucie Counties, Florida; however, the TOJ lies just south of Martin County and is included in the study.

Specific conductance, chloride, and dissolved solids were documented in well PB-1196 (Table 2), which is a dual-zone monitoring well located within the TOJ BWRO wellfield. This well system is used in monitoring an injection well.

Specific conductance is shown to range from 6,110 at a depth of 490 m to 13,000 at a depth of 352 m [18]. A 1991 study found the aquifer transmissivity to be 853 m^2/d [17]. The storage coefficient and leakance values were not calculated or could not be determined from the constant rate test performed. However, using the steady-state confined aquifer model, a leakance of $6.02 \times 10^{-3}\ d^{-1}$ was estimated [17]. There is a wide distribution of dissolved chloride concentrations in the upper Floridan aquifer near the production wellfield around the Martin and Palm Beach County lines, ranging from 1,800 to 6,000 mg/L (Fig. 5).

Both fresh and brackish water sources supply the TOJ water treatment facilities. Freshwater from the Surficial Aquifer System supplies the NF and ion exchange treatment

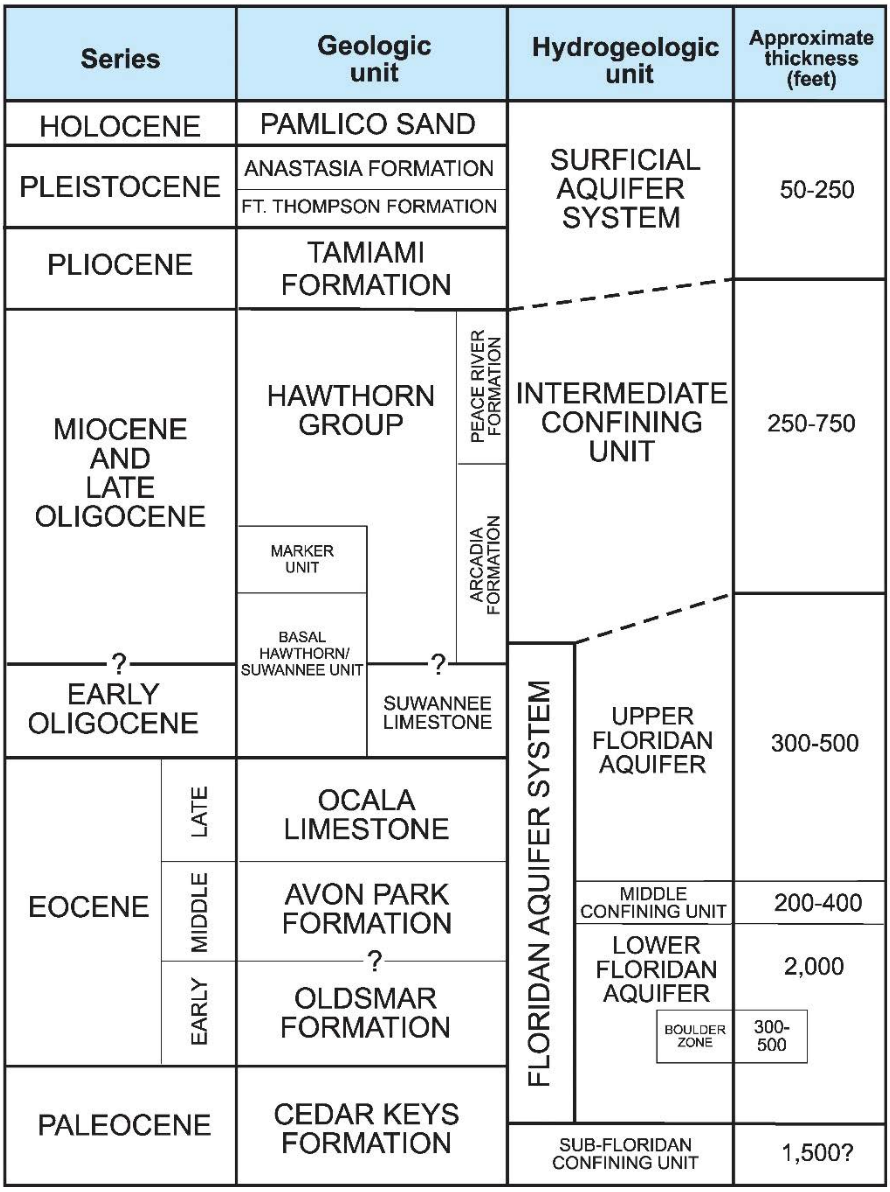

Fig. 3. Generalized geology and hydrogeology in Martin and St. Lucie Counties [18]. Note that the TOJ lies just south of Martin County and was included in this study.

plants, while brackish raw water from the upper Floridan aquifer supplies the RO plant [1]. During the dry season, the freshwater supply from the Surficial Aquifer System can become strained [23]. The brackish water supply and corresponding RO plant are primarily utilized during the dry season to mitigate impacts to the Surficial Aquifer System, such as wetland impacts and potential saltwater intrusion. Since the NF plant has a lower operating cost than the BWRO operation, the Surficial Aquifer System is prominently utilized during the wet season. The combined Surficial Aquifer System wellfield includes 45 production wells that can produce about 57.2 m^3/min. Older wells are generally located closer to the treatment facility. The oldest reported installed wells date back to 1974, with the other wells ranging in age from 5 to 45 y in 2019.

There are 11 in-service production wells (Fig. 2) that supply brackish water to the RO plant from the upper Floridan aquifer [1]. Fig. 6 shows an east-west hydrogeological section, and Fig. 7 demonstrates the relationship between the gamma-ray geophysical log, flow zones, stratigraphy, and hydrogeologic units for well PB-1197 in northeastern Palm Beach County. Note that well PB-1197 is in the TOJ upper Floridan Aquifer System reverse osmosis wellfield.

3.2. Initial groundwater modeling of the wellfield

A water supply study was conducted in 1992 to test the performance of the upper Floridan aquifer wellfield. Groundwater and solute transport modeling were conducted to evaluate various hydrogeologic scenarios

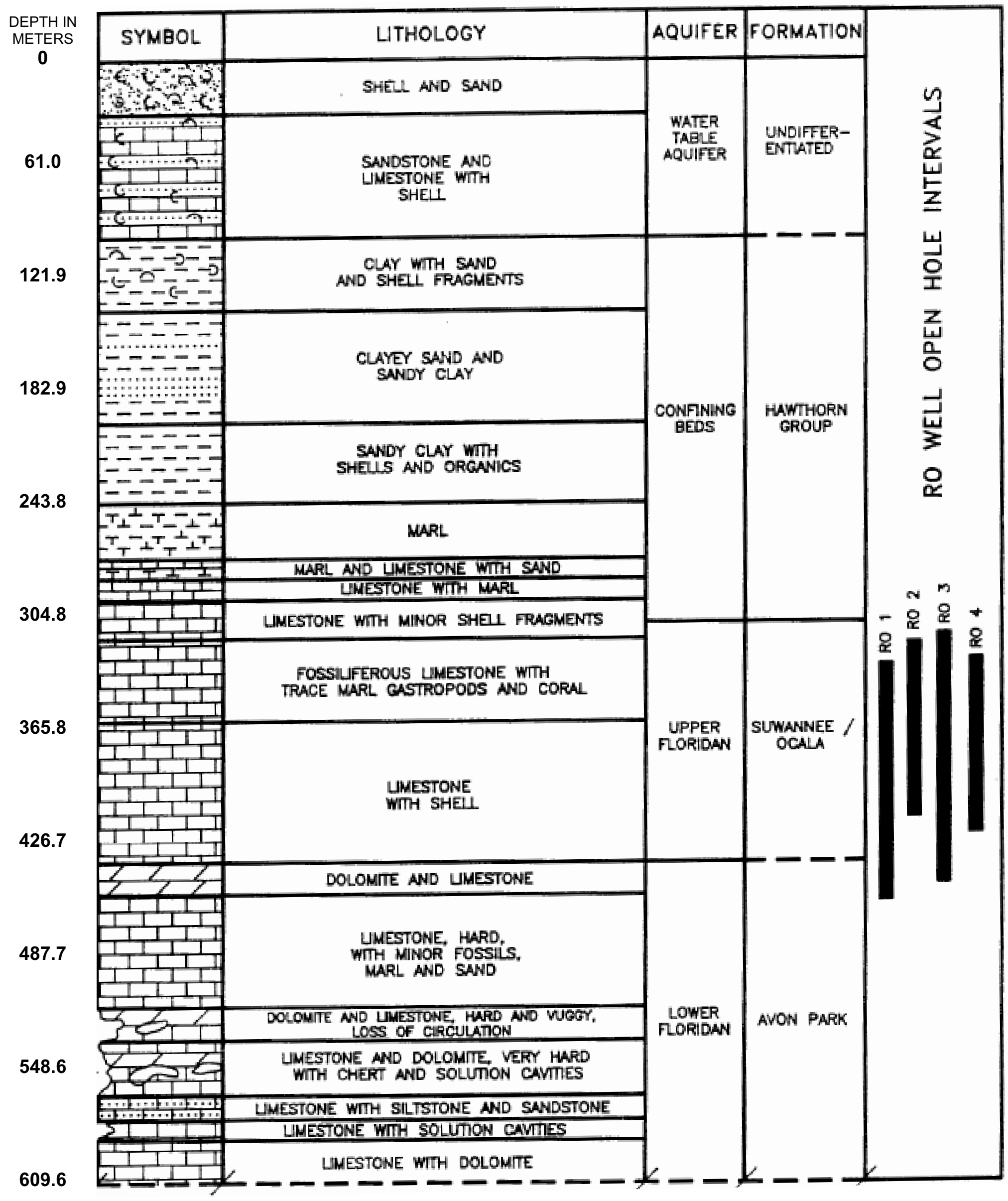

Fig. 4. Lithology at the Loxahatchee River Environmental Control District Injection Well, located approximately 1,006 m southwest of RO-1 [24].

and wellfield pumping rates [24]. Four dissolved chloride concentrations solute transport modeling scenarios were conducted. Two of the scenarios predicted chloride concentration changes from January 1992 to January 2006 utilizing the best estimate values for transmissivity and leakance from a distance of both 193 and 6.8 km from seawater at the shoreline. The other two scenarios utilized conservative transmissivity and leakance values for the same time and distance ranges. As the TOJ facility and corresponding wellfield are located about 4.95 and 11.55 km from seawater, the 6.8 km distance scenario was referenced. The number of production wells utilized in the modeling was assumed to increase from the initial four in the year 1992 to thirteen by the year 2006 [24].

4. Results

4.1. Feed water quality and pumping rate variations over time

Pumping rates were compared with dissolved chloride concentrations from January 2013 to December 2019, although water quality data were only available from May 2014 to December 2019. The initial dissolved chloride concentrations varied from 2,200 to 4,100 mg/L in in the wellfield with the lowest and highest values occurring in wells RO-13 and RO-6, respectively.

Analysis of the water quality changes with pumping and time is shown in Fig. 8. Over the first 5 y of operation, the highest increase in dissolved chloride change occurred in wells RO-2 and RO-3, which are located in the closest

Table 2
Water quality data collected from known intervals in wells from the Floridan Aquifer System [18,19]

Local well number	Date	Depth to bottom of open interval or depth or well (m)	Specific conductance (microsiemens per centimeter at 25°C)	Chloride (mg/L)	Dissolved solids (mg/L)
PB-747	6/19/1974	302 to 390	6,400	1,800	4,060
PB-1196	9/24/1993	352	N/A	4,000	N/A
PB-1196	9/24/1993	490	N/A	2,020	N/A
PB-1196	6/5/2020	352	12,890	3,800	7,942
PB-1196	6/5/2020	490	6,110	1,700	3,484
PB-1196	7/17/2001	352	13,000	3,800	8,290
PB-1196	7/17/2001	490	6,350	1,760	3,890

Note that PB-1196 is a dual-zoned monitoring well.

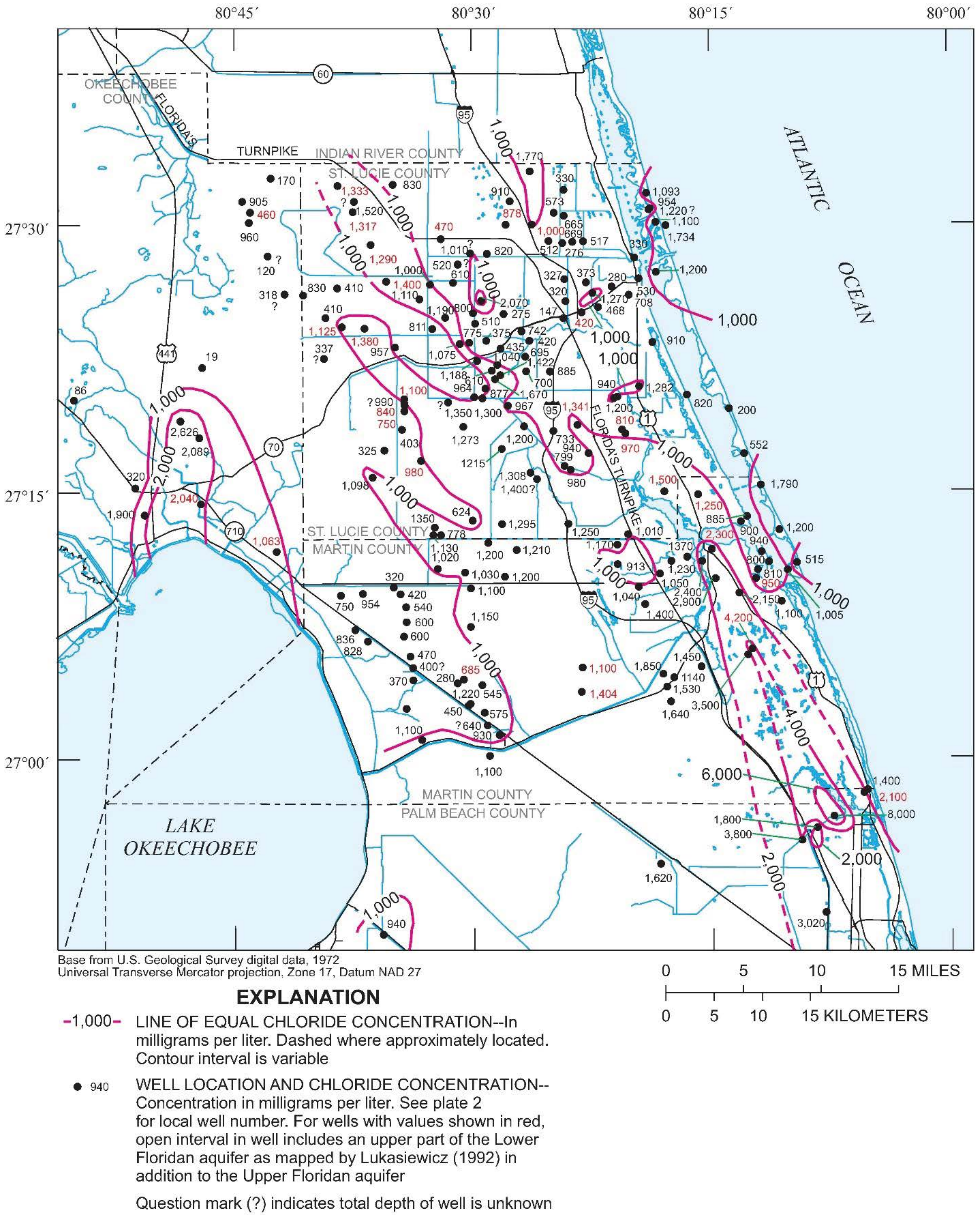

Fig. 5. Distribution of chloride concentration in the Upper Floridan Aquifer [18].

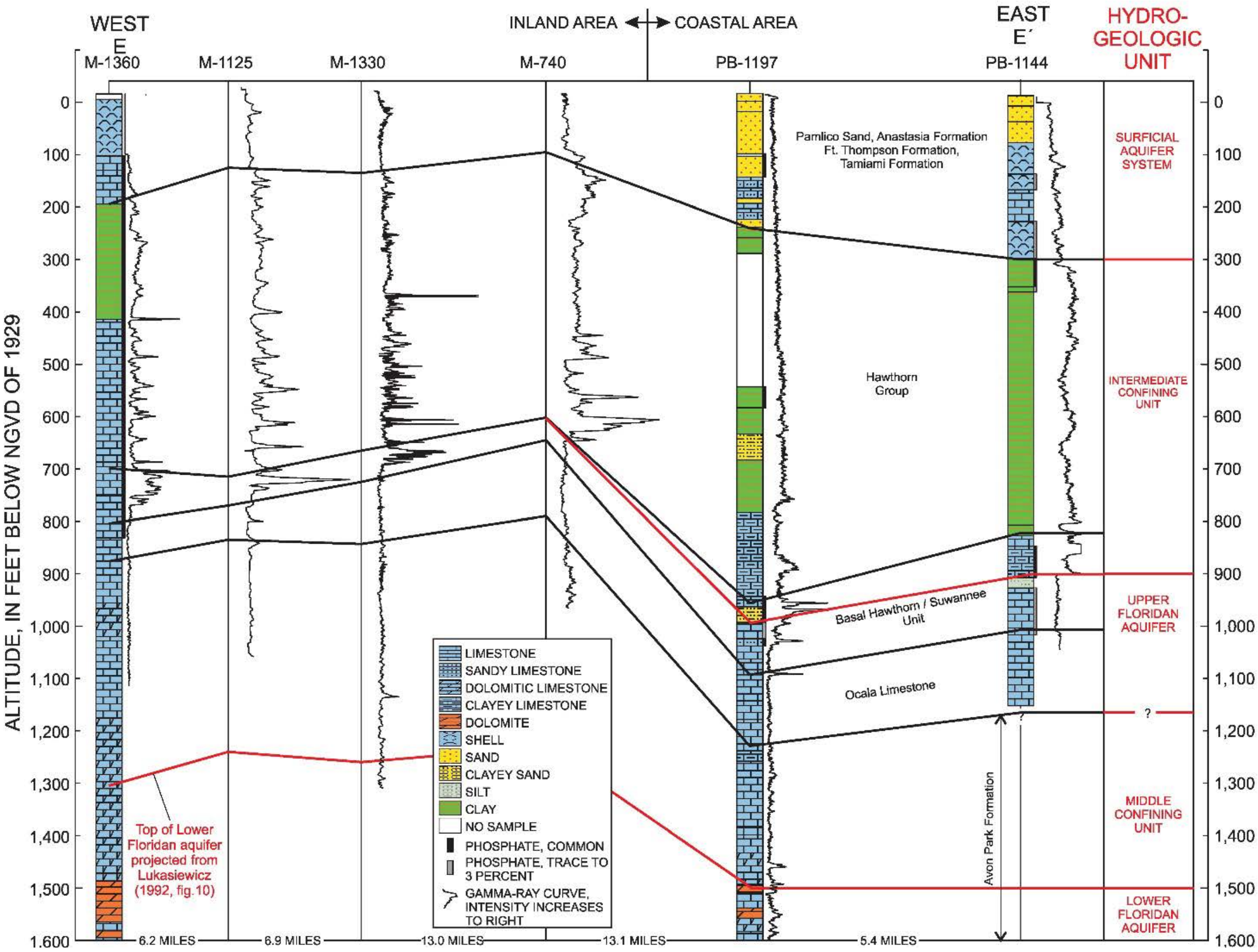

Fig. 6. East-west hydrogeological section "E-E" in the National Geodetic Vertical Datum of the year 1929 [18]. Note that well PB-1197 is in the TOJ upper Floridan Aquifer System reverse osmosis wellfield.

proximity to the Atlantic Ocean. Note that well RO-4, located at the BWRO plant, is prone to sand and silt production and has not been used for production [1]. Historically, in well RO-1, the dissolved chloride and TDS concentrations at 339 m (1,111 ft) below the land surface were 1,950 and 6,200 mg/L in the year 1991; however, the concentrations were 2,400 and 7,500 mg/L at a depth of 457 m (1,500 ft). Other wells demonstrate a reversal (decrease) in salinity over time [17]. A series of regression analyses are shown in Fig. 8 along with the R^2 values of the trendline and the *p*-values.

The scatter in the dissolved chloride data is rather great, resulting in generally low R^2 values. Apart from wells RO-2 and RO-3, the *p*-values are in excess of 0.05, which indicates that the trendline calculated from the regression analysis is not statistically significant for nine of the eleven wells. Therefore, the use of the equations for the lines are useful, but may not be a reliable means to project future trends.

4.2. Prediction of the long-term water quality changes through linear regression

There is commonly a linear relationship between monthly pumpage and dissolved chloride concentration, although this relation can also be exponential or a combination of regression patterns. Projected dissolved chloride concentrations for all of the existing production wells are given in Table 3. Water quality projections of 5-, 10-, and 20-y projections of the water quality for wells with a linear trend are considered reasonably valid considering the aquifer type. Projected changes in groundwater salinity changes can, therefore, be analyzed through performing a linear regression on the data. Forty-year projections are less confident and are better approximated through a three-dimensional solute transport modeling [10]. Historically, the feed water quality from the wells increased in dissolved chloride concentration by an average of 314 mg/L (605 mg/L TDS) from the year 2014 to 2019. The projected 20-y change in dissolved chloride concentration was found to average an increase of 1,268 mg/L (2,439 mg/L TDS) from 2019 to 2039 above the average 2019 starting point concentration of 3,264 mg/L (6,277 mg/L TDS).

5. Discussion

5.1. Cause of increased groundwater salinity over time

Along the coast in northern Broward and Palm Beach Counties, similar reversals in salinity with depth within the brackish-water zone of the upper part of the Floridan

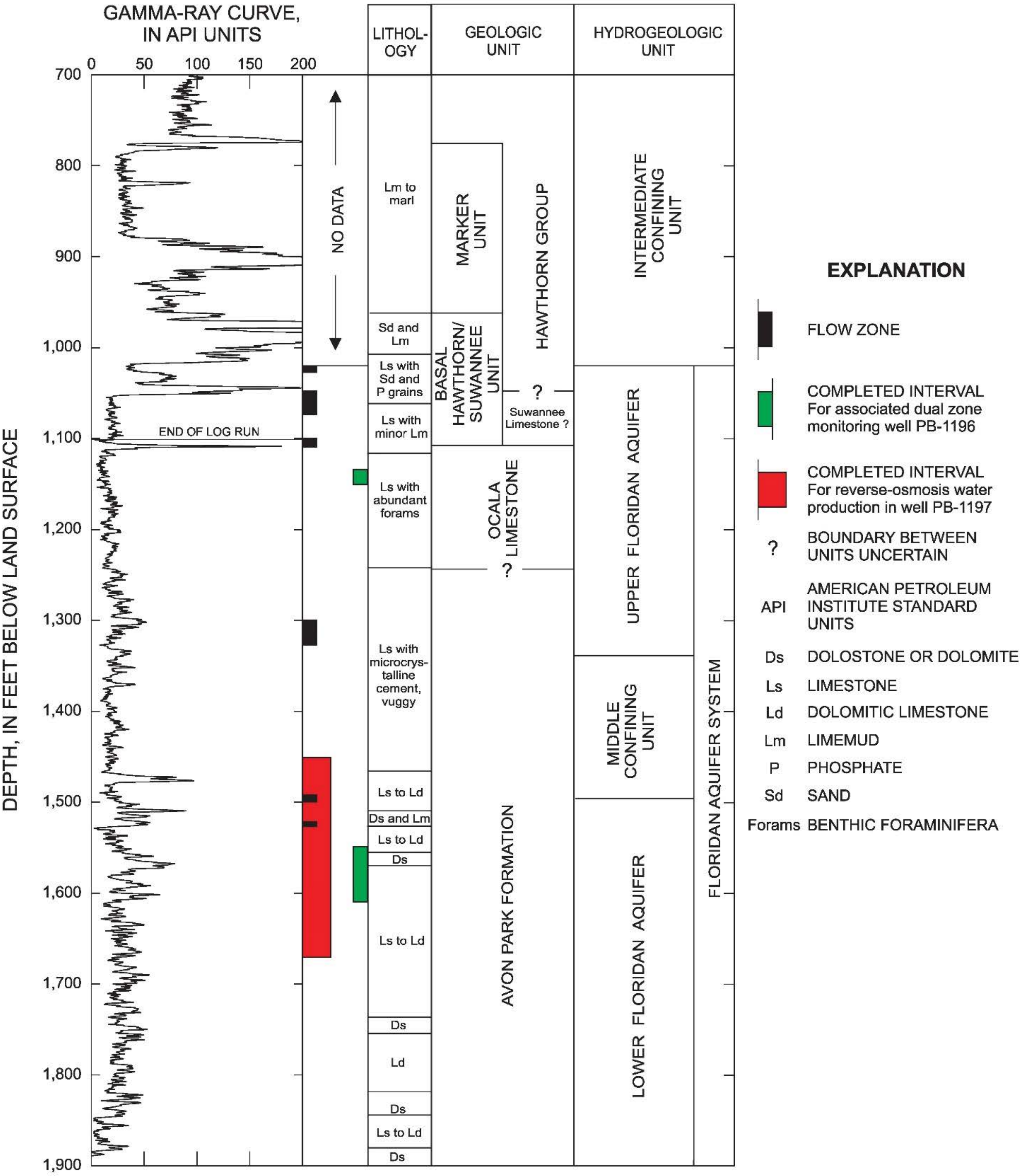

Fig. 7. Gamma-ray geophysical log, flow zones, stratigraphy, and hydrogeologic units for well PB-1197 in northeastern Palm Beach County. Flow zones determined from flowmeter and temperature logs and flow measurements while drilling. Note that well PB-1197 is in the TOJ upper Floridan Aquifer System reverse osmosis wellfield [18].

Aquifer System have been found in the past. An example is shown in well PB-1196, where the chloride concentration was 3,800 mg/L in water from the upper monitoring zone at a depth interval between 347 and 352 m below the ground surface. In comparison, a reading of 1,760 mg/L was recorded from the lower monitoring zone at a depth interval between 472 and 490 m on July 17, 2001. In the southern coastal area of the upper Floridan aquifer, the anomalous vertical distribution of salinity in the brackish-water zone may be related to the abnormal depth of the brackish-water zone base.

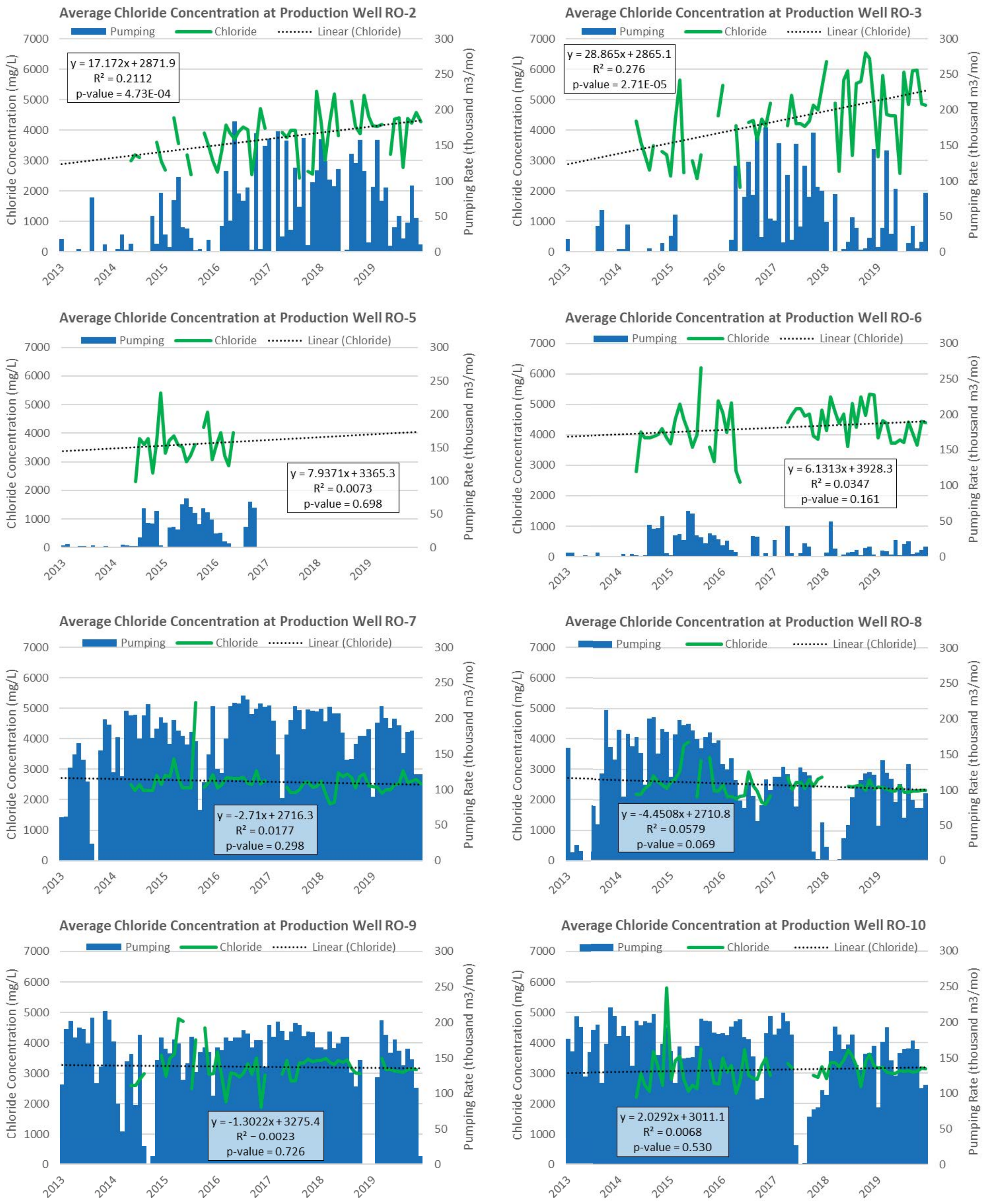

Fig. 8. Continued

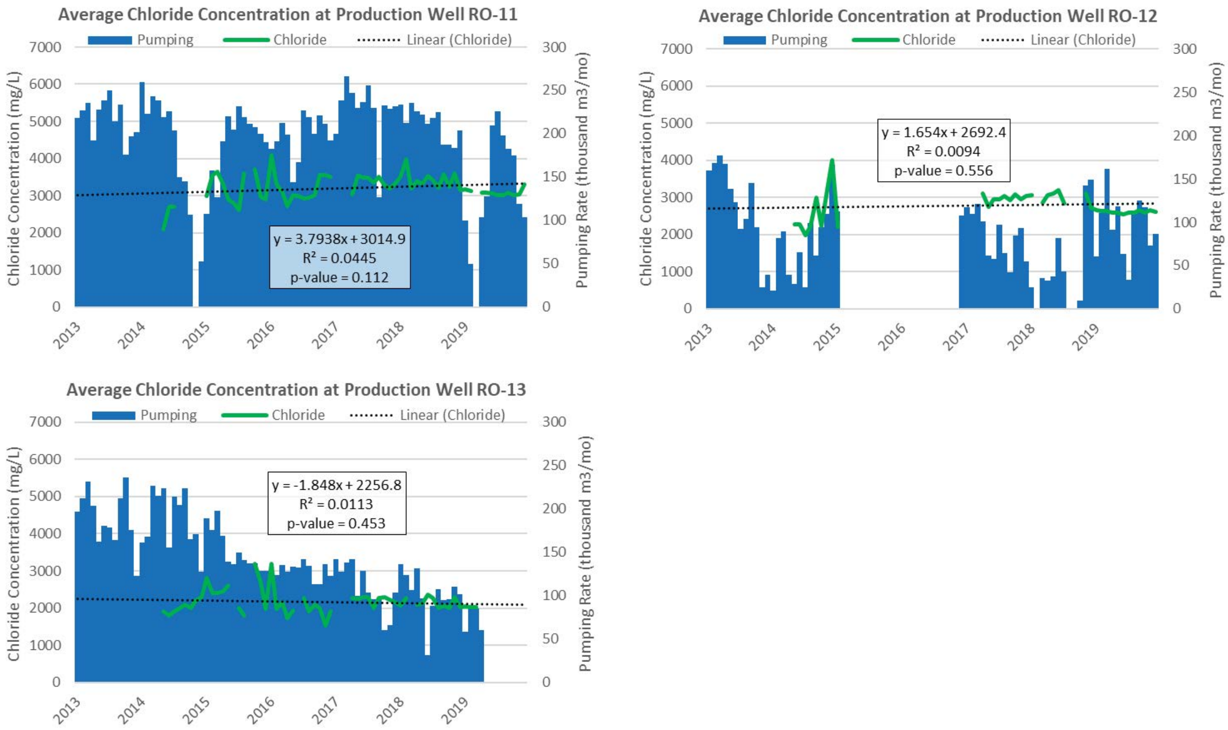

Fig. 8. Graphs depicting the changes in dissolved chloride concentrations (in mg/L) in time with the monthly pumpage data from all production wells.

This reversal in salinity could be explained by greater salinity flushing from the lower part of the upper Floridan aquifer by less saline recharge water from an increased gradient, facilitated by the higher hydraulic conductivity [18].

The production aquifer is semi-confined or leaky. As the regional confining unit thickness above the production aquifer is much greater than the confining layer below the aquifer, during pumping, the recharge to the production aquifer is directed upwards from underlying and more saline aquifers. The assumed conceptual model (Fig. 9) is appropriate if there is no significant downward recharge, breaches of the confining units, or dramatic changes in the aquifer hydraulic properties delineated in the near vicinity of the wellfield area [25].

5.2. Comparison of observed changes in water quality with the past modeling

A comparison of observed changes in water quality can be made in comparison with the solute transport modeling predictions made in the year 1992. From Table 4, a chloride concentration increase of 550 mg/L (1,057 mg/L TDS) to 1,730 mg/L (3,327 mg/L TDS) was predicted to occur within a 15-y span, which equates to a 37 to 115 mg/L increase per year [24]. This range compares favorably with the actual measured changes and the projection made using rate data collected from operation of the wells. In cross referencing, the historical data from the year 2014 to 2019, the average increase in chloride concentration was 63 mg/L per year (Table 3), which is within the predicted increase range modeled almost 20 y ago.

5.3. Future operational risk due to dramatic feed water salinity change

One of the most significant risks to the TOJ BWRO facility operation would be a rapid and inconsistent change in the wellfield water quality. In some cases, an alternative conceptual model is required to explain erratic changes in wellfield water-quality behavior during pumping. One such conceptual model was developed during analysis of the City of Clearwater Reservoir 2 facility where the water quality in the unconfined Surficial Aquifer System and the Floridan Aquifer System was inconsistent and rapidly increased in salinity during pumping. There were also considerable differences in the rate of salinity changes in the pumped water from differing production wells. This region of Pinellas County is prone to sinkholes, which can create karst conduits that provide a pathway through confining strata. Successful plant design and operation are challenging for a wellfield hydrogeology that includes karst conduits, as shown in Fig. 10. In this instance, the plant components and operation would need to be modified to treat a feed water supply with much higher salinity, such as seawater membranes [7]. The modeled and observed changes at the TOJ wellfield suggest that the proper conceptual model was applied to the system and a sudden change in water quality is likely not to occur in the future.

5.4. Impact on the BWRO design and operation caused by the long-term increase in feed water salinity

The TOJ approach to management of their utility system operation emphasizes long-range capital and financial planning, so that the water treatment plant, transmission

Table 3
TDS and dissolved chloride concentrations in the production well water towards the beginning of production, at the end of the year 2019, and projections to 40 y

Well No.	2014, CL-(mg/L)	2014, TDS (mg/L)	2019, CL-(mg/L)	2019, TDS (mg/L)	5 y, CL-(mg/L)	5 y, TDS (mg/L)	10 y, CL-(mg/L)	10 y, TDS (mg/L)	20 y, CL-(mg/L)	20 y, TDS (mg/L)	40 y, CL-(mg/L)	40 y, TDS (mg/L)
RO-2	3,200	6,154	4,192	8,062	5,345	10,278	6,375	12,260	8,436	16,222	12,557	24,148
RO-3	3,200	6,154	4,866	9,358	7,022	13,503	8,754	16,834	12,217	23,495	19,145	36,817
RO-6	4,100	7,885	4,382	8,427	4,811	9,252	5,179	9,960	5,915	11,375	7,386	14,205
RO-7	2,500	4,808	2,525	4,856	2,326	4,473	2,163	4,161	1,838	3,535	1,188	2,284
RO-8	2,600	5,000	2,360	4,538	2,070	3,981	1,803	3,467	1,269	2,440	201	386
RO-9	3,000	5,769	3,135	6,029	3,088	5,938	3,010	5,788	2,853	5,487	2,541	4,886
RO-10	3,000	5,769	3,162	6,081	3,303	6,353	3,425	6,587	3,669	7,055	4,156	7,991
RO-11	2,700	5,192	3,312	6,369	3,561	6,848	3,789	7,286	4,244	8,162	5,155	9,913
RO-12	3,000	5,769	2,664	5,123	2,931	5,636	3,030	5,827	3,228	6,208	3,625	6,972
RO-13	2,200	4,231	2,046	3,935	1,991	3,828	1,880	3,615	1,658	3,189	1,215	2,336

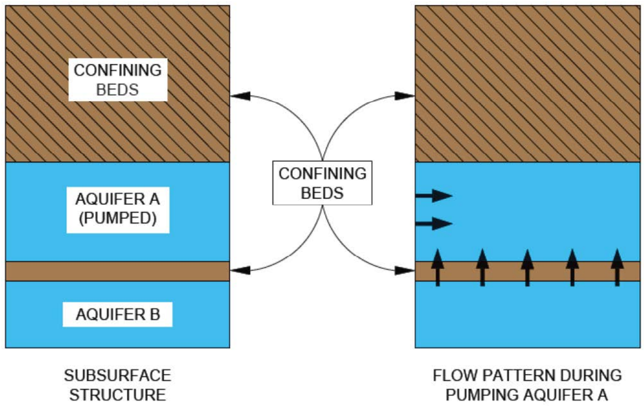

Fig. 9. Diagram of the upward recharge flow pattern of a brackish-water aquifer during pumping [9].

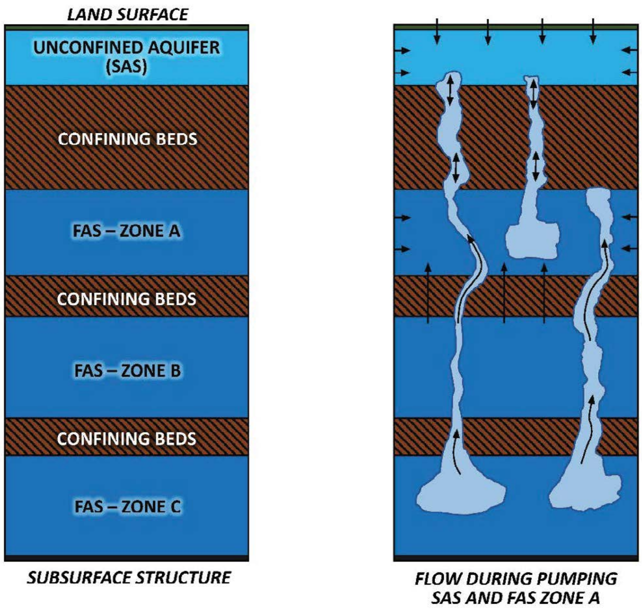

Fig. 10. An example of an alternative conceptual model that includes karst conduit connections through confining beds [7].

system, and wellfields are continually adapted to allow long-term efficient production of potable water. The original BWRO treatment facility was initially designed to treat raw water with a dissolved chloride concentration of up to 2,955 mg/L (TDS = 5.683 mg/L) [17]. Three RO plant modifications were planned to allow for continued use of the Floridan Aquifer System raw water supply as TDS increases over time. Phase 1 will entail the addition of Stage 2 feed pressure booster pumps or the replacement of the existing interstage energy recovery devices to boost pressure from Stage 1 concentrate to Stage 2 feed water. This first phase will allow for the treatment of raw water TDS concentrations from 4,700 to 7,300 mg/L. Phase 2 involves replacing membranes in all nine RO trains with high rejection and low energy membranes. The individual train recovery will be reduced from 75% to 70% but will allow for an increase in TDS in the raw water from 7,300 to 8,500 ppm.

Table 4
Chloride concentration change prediction from the year 1992 solute transport modeling [24]

Scenario characteristics		Chloride concentration (mg/L): best estimate transmissivity & leakance	Chloride concentration (mg/L): conservative transmissivity & leakance	No. of wells online
Distance to seawater (miles)		4.25	4.25	
	Jan-1992	2,450	2,450	4
	Jan-1993	2,470	2,560	7
	Jan-1994	2,530	2,710	7
	Jan-1995	2,526	2,750	9
	Jan-1996	2,570	2,870	9
	Jan-1997	2,560	2,880	11
	Jan-1998	2,600	2,990	11
Date	Jan-1999	2,590	2,990	13
	Jan-2000	2,630	3,110	13
	Jan-2001	2,680	3,250	13
	Jan-2002	2,730	3,400	13
	Jan-2003	2,790	3,570	13
	Jan-2004	2,860	3,760	13
	Jan-2005	2,930	3,960	13
	Jan-2006	3,000	4,180	13
Increase:		550	1,730	
Increase per year:		37	115	

Phase 3 includes the construction of a raw water booster pump station on the WTP site and the addition of a second pass RO treatment system for portions of Stage 2 permeate on each of the nine trains. This process modification will allow for operation with TDS concentration from 8,500 to 11,500 ppm by 2028. The TOJ also plans to upgrade the concentrate treatment facility of the RO plant by modifying the existing degasifiers to improve efficiency and flexibility. If the performance of the existing degasifiers is inadequate, the TOJ plans to add additional degasifiers for RO permeate treatment. Improvements to the wellfields are also planned through the addition of four upper Floridan aquifer wells. By lowering the individual pumping rates and spreading the pumping over a larger wellfield area, the stress on the existing wellfield will be reduced [1].

The process flow diagram for the TOJ BWRO water treatment facility is given in Fig. 11. There are two banks and nine trains that contribute to producing 62,281 m^3/d of potable water [15]. As a means of recycling and reuse of the process by-products, the brackish water concentrate from the RO process is treated, mixed in a canal, and discharged into the Loxahatchee River. This recycling process was approved by the Florida Department of Environmental Protection and the United States Environmental Protection Agency [2].

Based on the monitoring data over the past 5 y and projected over the next 20 y, the predicted TDS change will bring the average feed water to 8,717 mg/L. The town plans to revise plant operation and wellfield characteristics to treat TDS concentrations from 8,500 to 11,500 mg/L. It appears that the long-term TDS increase in the feed water quality will not significantly affect the ability of the TOJ facility to meet future water supply demand successfully.

6. Conclusions

A long-term increase in the TDS of the groundwater that supplies feed water to a BWRO plant is typical of most systems designed and operating in Florida. Groundwater flow and solute-transport modeling of the source aquifer are commonly conducted to project the change in feed water quality characterization over a 20- to 40-y period. The modeling results are relied upon to assure that the BWRO plant can successfully operate for the expected useful lifespan. This type of modeling was conducted during the early stages of implementation of BWRO at the Town of Jupiter. The projected annual rate in change of dissolved chloride concentration was between –4.5 and 50.1 mg/L (–8.7 to 96.3 mg/L TDS). This range compares favorably with the actual measured changes and the projection made using rate data collected from operation of the wells. The conceptual aquifer model of a system that recharges from the bottom upwards was verified at the Town of Jupiter BWRO facility.

The BWRO plant at the TOJ water treatment facility was designed to treat a feed water quality TDS of 2,955 mg/L. The 20-y projection of the pumping and water quality data

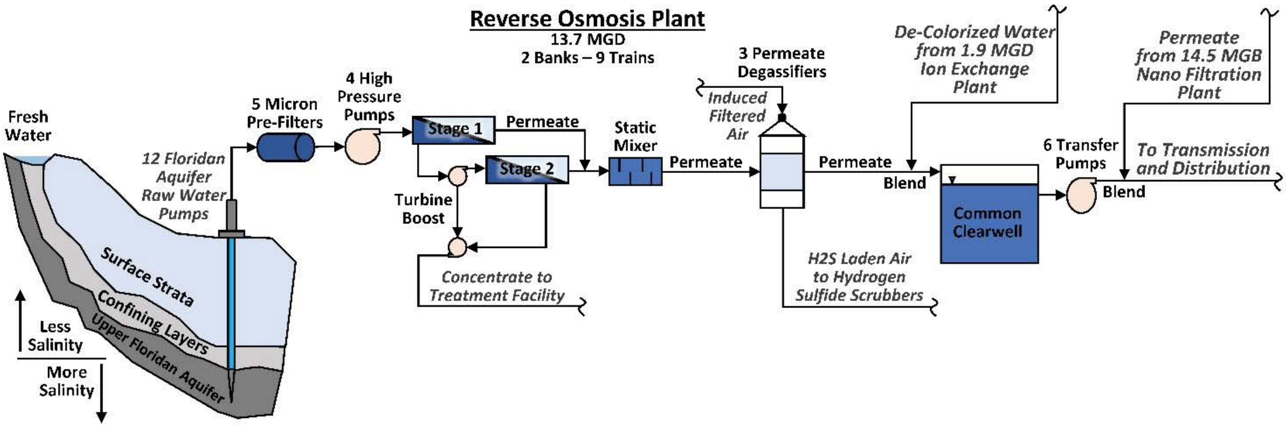

Fig. 11. Process flow diagram for the Town of Jupiter BWRO water treatment facility [15].

from the year 2014 to 2019 suggests an average increase of TDS to 8,717 mg/L. The TOJ has a three-phased plan to modify the wellfield and treatment facility to allow for operation with TDS concentration from 8,500 to 11,500 mg/L by the year 2028. Future research efforts should fill the gaps in data, if available, which include water quality data for all of 2013, and portions of 2014 (January, February, March, and April), 2015 (September), and 2017 (January February, and March).

The rate of pumping-induced salinity change in production wells can be mitigated by reducing the quantity of water being withdrawn from existing wells. Additional wells should be added to allow for flexibility in wellfield operation in producing the required permeate water. Utilization of the BWRO facility in conjunction with the nanofiltration and ionic exchange process mitigates the overuse of the limited freshwater resources while meeting the potable water demands and promoting environmental preservation. The resource management and operational approach of the TOJ water treatment facility is an excellent example of a community that is committed to pursuing innovative approaches for the supply of potable drinking water when utilizing a leaky aquifer system as a feed water source. The Town of Jupiter is an example of how to properly manage a BWRO system that has long-term changes in feed water quality.

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