Water Quality Modeling and Alternatives Analysis for a New Peace River Intake

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Surface water quality modeling and systemwide reliability modeling were performed by the Peace River Manasota Regional Water Supply Authority (authority) to inform the siting of a new intake on the Peace River. Temporally and spatially variable river flows and water quality were explored to quantify the associated impact on the authority's ability to meet system demands at target water quality. These efforts demonstrate the importance of considering both raw water quantity and quality with respect to treatment barriers and overall system limitations when projecting potable water supply reliability under current and potential future conditions. The approach for incorporating modeling results and other factors into the decision-making process for intake siting and design is discussed.

Background

The authority was established to meet the regional water supply needs of its four member governments: Charlotte, DeSoto, Manatee, and Sarasota counties. In addition, the authority also serves the City of North Port as a customer and maintains an interconnection with the City of Punta Gorda.

The authority partners with its member governments and customers to provide drinking water to a population of over 1 million. The authority's existing water supply system at the Peace River facility (PRF) includes two reservoirs, raw and finished water pipelines, a river water intake pump station on the Peace River, a 51-mil-gal-per-day (mgd) water treatment plant (WTP), and an aquifer storage and recovery (ASR) system.

Raw water is withdrawn from the Peace River and stored in two reservoirs with a combined storage capacity of 6.5 bil gal. Water from the reservoir system is treated at the WTP where the finished drinking water is delivered to customers through approximately 80 mi of large-diameter transmission mains. Excess finished water may also be directed to and stored in the ASR system during wet periods to be subsequently withdrawn during dry periods for reservoir augmentation.

In response to increasing regional demands and the demonstrated benefits of existing reservoirs, the authority is now undergoing siting and feasibility studies for a third reservoir, Peace River Reservoir No. 3 (PR3), and an additional river water intake (Figure 1). These additional assets would further the authority's ability to harvest and store large volumes of water during relatively short periods of availability. The PR3 siting and feasibility study includes evaluation of conceptual sizing, siting, wetland mitigation, operational configurations, and facility requirements.

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Siting of the new river intake must be informed by temporally and spatially variable flow and water quality in the Peace River, which largely results from competing freshwater and tidal influences. Historical water quality data show that the existing intake location (Figure 2) is more prone to elevated total dissolved solids (TDS) concentrations than upstream locations due to proximity to the coast. The TDS is an important raw water quality parameter for consideration because

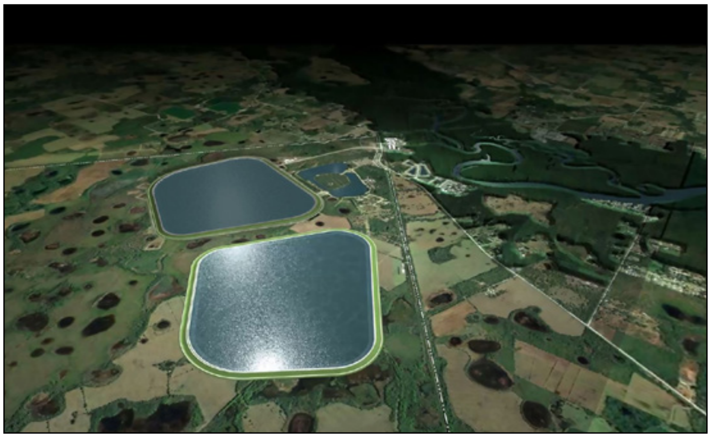

Figure 1.Peace River Manasota Regional Water Supply Authority's existing and forthcoming reservoir system. The existing Reservoirs No. 1 and No. 2 are in the background; the forthcoming Reservoir No. 3 rendering is in the foreground. *(photo: HDR)*

Figure 2. Existing intake on the Peace River. *(photo: Peace River Manasota Regional Water Supply Authority)*

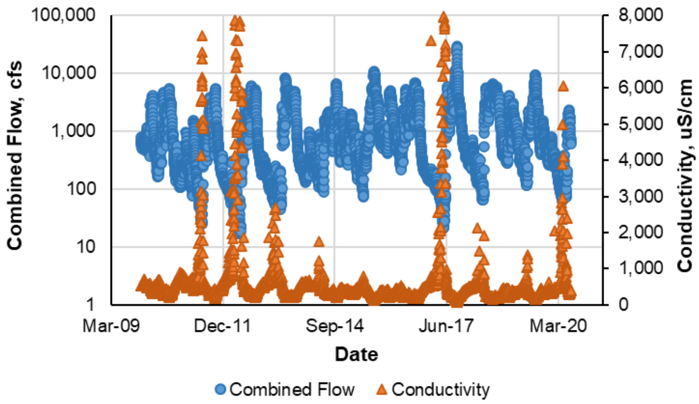

Figure 3. Gaged flow and conductivity in the Peace River upstream of the exiting intake.

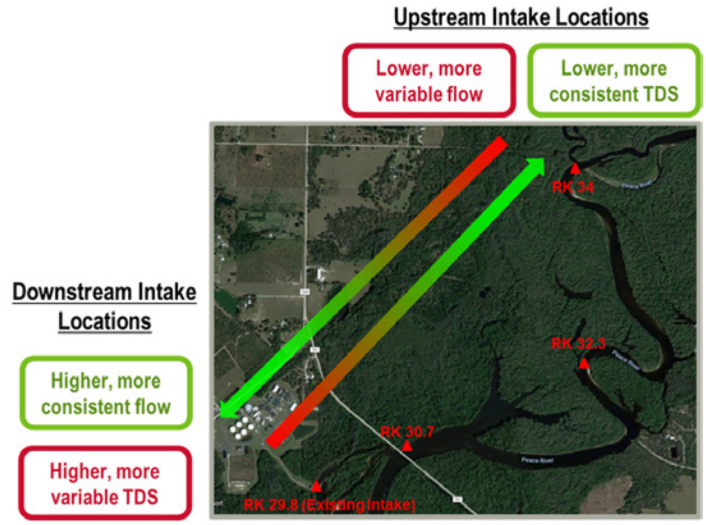

Figure 4. Aerial image of the Peace River with four potential locations for the new intake shown with associated river kilometer values.

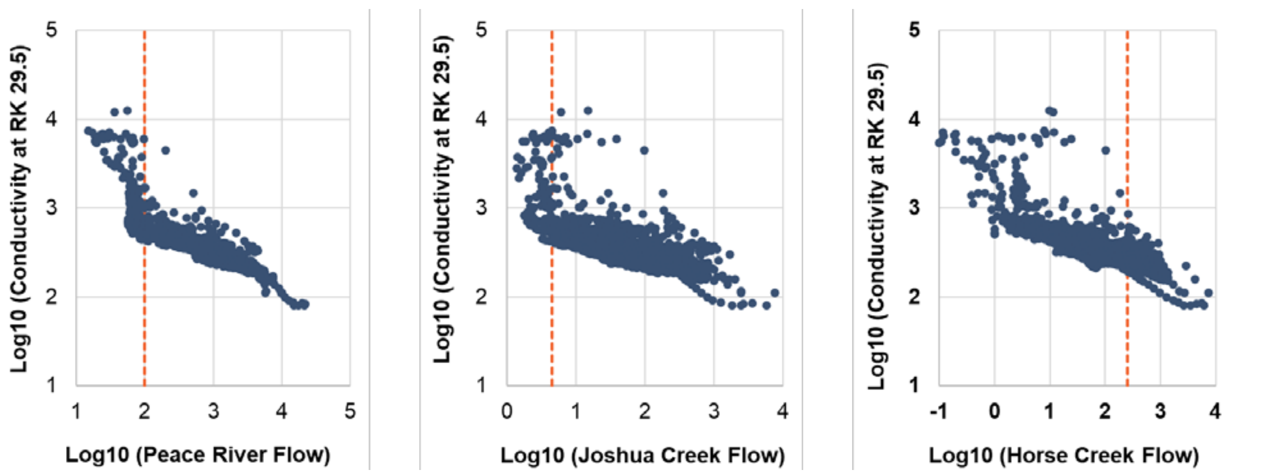

Figure 5. Log of conductivity (MicroSiemens per centimeter) at exiting intake locations versus log of flow (cubic feet per second) at three upstream river locations showing modeled breakpoints for segmented regression

the authority may forego available river water withdrawals if TDS concentrations are high due to a lack of treatment barriers for TDS removal at the WTP.

For example, Figure 3 shows average conductivity, which is a surrogate water quality measurement for TDS, and the combined gaged flow upstream of the existing Peace River intake from December 2009 to June 2020, as measured and recorded by the U. S. Geological Survey (USGS). Both flow and conductivity show seasonal variability, with conductivity generally peaking in March to early June and flow generally peaking between July and October. During this historical period, the authority was able to withdraw river water on 84 percent of the days, considering constraints related to minimum acceptable river flows and maximum acceptable conductivity values.

The authority is considering four potential sites for the new river intake (Figure 4). Site selection depends on each site's projected impact on systemwide reliability (i.e., ability to meet regional demands and ability to deliver targeted water quality), property implications, proximity to hazards, accessibility, and other criteria.

This article focuses on the projected impact of intake siting on systemwide reliability due to river water quality differences.

Methods

Historical USGS, National Oceanic and Atmospheric Administration (NOAA), and authority data, as well as newly collected data, were combined to create a water quantity and quality database for the Peace River. These data were used to develop a regression model for the prediction of flow and water quality at each intake location option under current and potential future conditions (e.g., sea level rise and changes in precipitation).

The authority's systemwide reliability planning tool, SUMDAT (system utility management decision analysis tool), was updated with the newly developed TDS models at each intake location to predict the impact of several variables on the authority's ability to meet system demands at target water quality. The SUMDAT is a daily mass and solute balance model that predicts system performance at a given demand considering hydrologic and associated water quality variability, capacities of individual system components, operational constraints, and other rules and variables.

The main design variables under evaluation in this study were reservoir size and intake location. An additional operational variable was also evaluated, which was whether to limit river water withdrawals based on TDS.

Findings

The *R* statistical software was used to develop and test several forms of regression equations to predict river water TDS at individual intake locations using historical river water quality data, historical river

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flows, and other historical conditions. The streamflow and conductivity time series were log-transformed due to their log-normal distribution. Initial testing with a multivariate linear regression equation resulted in a poor fit for higher conductivity (and low streamflow) values. A segmented or broken line linear regression model was investigated using the *R package segmented*.

The segmented model represents a relationship in which the effect of the response variable changes across a threshold value and was found to improve model fit for high conductivity values. In this case, the relationship between conductivity and freshwater flow changes from the low-flow regime (where the conductivity is dominated by the tidal influence) to the high-flow regime (where the tidal influence is negligible and freshwater dilution dominates). Breakpoints for the three flow time series were identified based on visual inspection of data and testing with the segmented package (see Figure 5).

The final rule form for the linear regression equations was:

$$
\begin{aligned}
&Log_{10}\,[Conductivity] = \\
&\beta_0 \\
&+\beta_{PR1}\,Log_{10}\,[Q_{PR}] + \beta_{PR2}\,(Log_{10}\,[Q_{PR}] - Log_{10}\,[Q_{PR}^{Br}]) \\
&\cdot (Q_{PR} \geq Q_{PR}^{Br}) \\
&+\beta_{JC1}\,Log_{10}\,[Q_{JC}] + \beta_{JC2}\,(Log_{10}\,[Q_{C}] - Log_{10}\,[Q_{JC}^{Br}]) \cdot \\
&(Q_{JC} \geq Q_{JC}^{Br}) \\
&+\beta_{HC1}\,Log_{10}\,[Q_{HC}] + \beta_{HC2}\,(Log_{10}\,[Q_{HC}] - Log_{10}\,[Q_{HC}^{Br}]) \cdot (Q_{HC} \geq Q_{HC}^{Br}) \\
&+\beta_{SL}\,H_{SL}
\end{aligned}
$$

Where:

- Q_{PR}, Q_{JC}, and Q_{HC} are observed flows in Peace River, Joshua Creek, and Horse Creek, respectively,
- β_0 is the model intercept,
- β_{PR1}, β_{JC1}, and β_{HC1} are the regression coefficients (slopes) for three upstream gaged flow locations (Peace River, Joshua Creek, and Horse Creek, respectively) for flows that are less than the corresponding low-flow breakpoint,
- β_{PR2}, β_{JC2}, and β_{HC2} are the change-in-slope values for flows that are greater than the corresponding low-flow breakpoint,
- Q_{PR}^{Br}, Q_{JC}^{Br}, and Q_{HC}^{Br} are modeled low-flow breakpoints for Peace River, Joshua Creek, and Horse Creek, respectively,
- H_{SL} is observed sea level, and
- β_{SL} is the regression coefficient for sea level.

The β values in the final rule form change depending on the assumed location of the new intake.

The regression described was used to develop time series predictions for conductivity; the predictions were based on historical streamflows at the three gaged river locations and an assumed constant sea level condition. Observed and predicted conductivity values for the existing intake location are shown in Figure 6. Predicted conductivity values generally match well with historical observations and the segmented regression captures conductivity peaks during low-flow periods.

Figure 7 shows a comparison of predicted TDS concentrations at the existing intake

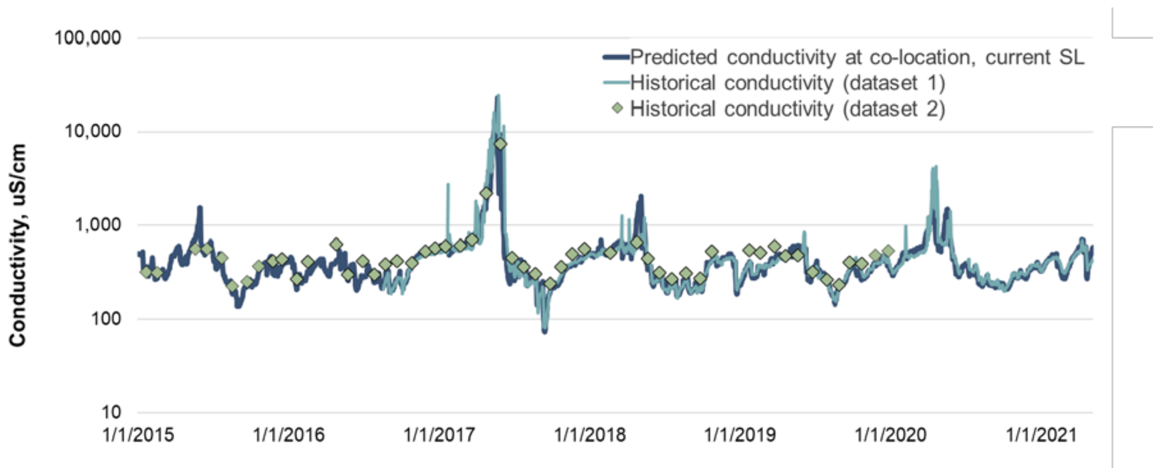

Figure 6. Observed and predicted conductivity values at the existing Peace River intake location.

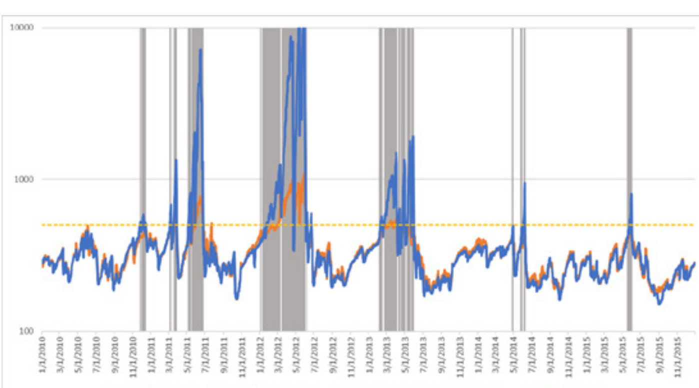

Figure 7. Predicted total dissolved solids concentrations at existing intake location and furthest upstream intake location option at existing sea level conditions.

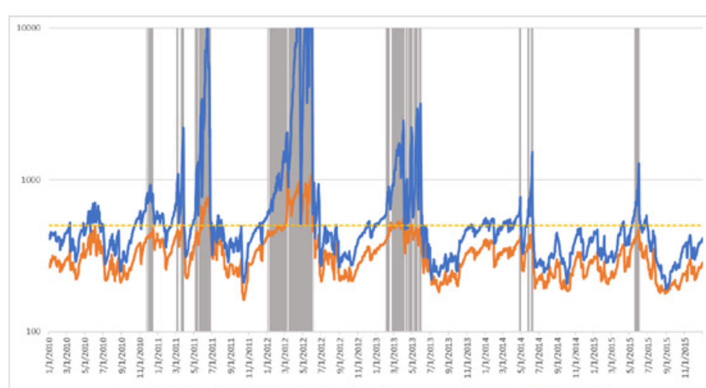

Figure 8. Predicted total dissolved solids concentrations at existing intake location and furthest upstream intake location option at 5 feet of sea level rise.

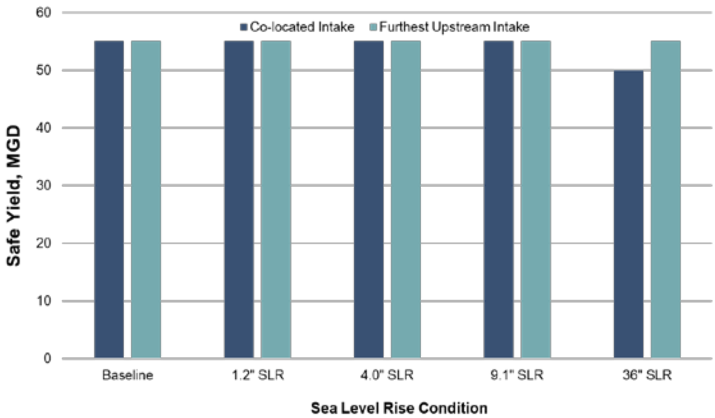

Figure 9. Systemwide reliability safe yield results for two intake location options at baseline and potential future sea level rise conditions.

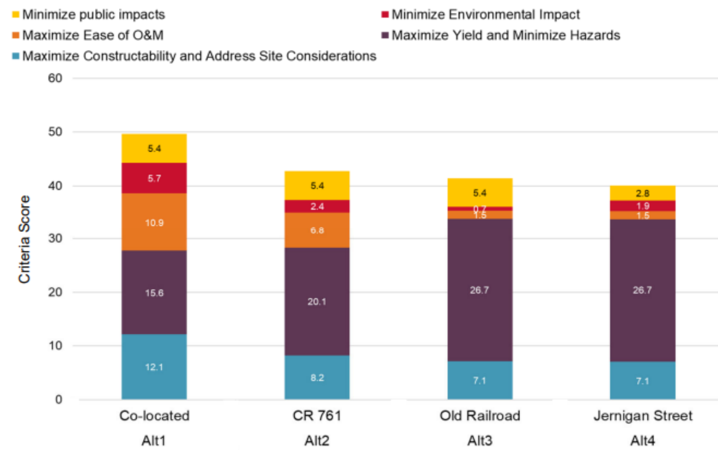

Figure 10. Multicriteria decision analysis results for the intake siting decision.

location (river kilometer [RK] 29.5) and the furthest upstream intake location option (RK 34) at current sea level. These predictions show that TDS levels at the existing intake location are anticipated to be far greater than those at the upstream intake location option, particularly during low-flow conditions (grey shaded areas).

Figure 8 shows that this difference in predicted TDS concentrations at the colocated and upstream intake location options becomes even more significant when potential future sea level rise is brought into the equation. To quantify the extent to which these differences in anticipated TDS concentrations at the intake location options impact overall system reliability, these newly developed regression models were incorporated into the authority's SUMDAT model.

The main objective of the SUMDAT outputs analysis was to determine the extent to which an upstream intake location could benefit system reliability considering its potential reduced sensitivity to sea level, and thus, reduced frequency and magnitude of elevated TDS concentrations in the river.

Figure 9 shows the predicted safe yield of the authority's water supply and treatment system, assuming that the new Peace River intake is colocated with the existing intake versus located at the furthest upstream intake location option. Safe yield was defined as the constant regional demand at which the system would be able to meet regional demands at least 99.5 percent of the time from a quantity perspective and deliver water with a TDS concentration less than 500 mg/L at least 95 percent of the time. Figure 9 also shows that the safe yield for the system is estimated to be 55 mgd for both intake location options until up to 9 in. of sea level rise. The upstream intake location option is only anticipated to benefit safe yield at the highest sea level rise condition of 36 in.

Figure 11. Rendering of the expanded intake on the Peace River. *(photo: HDR)*

The systemwide reliability results in Figure 9 demonstrate that, although TDS is predicted to be higher at the existing intake location than at the upstream intake location option, these TDS differences are largely under low-flow conditions when the authority is not permitted to withdraw river water.

Conclusions

Overall, siting of the new Peace River intake was a critical component of the PR3 siting and feasibility study. Water quality modeling and systemwide reliability modeling enabled an informed decision-making process for current and potential future sea level rise, and precipitation conditions

Figure 10 shows the multicriteria decision analysis scoring for the four intake location options under consideration by the authority. The colocated siting location (Alternative 1) has the highest overall benefit score due to its anticipated ability to maximize ease of operation and management, maximize constructability, and minimize environmental impact. The two furthest upstream intake location options (Alternatives 3 and 4) scored the highest for maximizing yield and addressing water quality limitations due to lower predicted TDS concentrations under the 36-in. sea level rise scenario, as well as for being upstream of a road river crossing.

The authority's board has approved colocation of the new expanded Peace River intake (Figure 11) with the existing Peace River intake based on the findings of this evaluation. ◊