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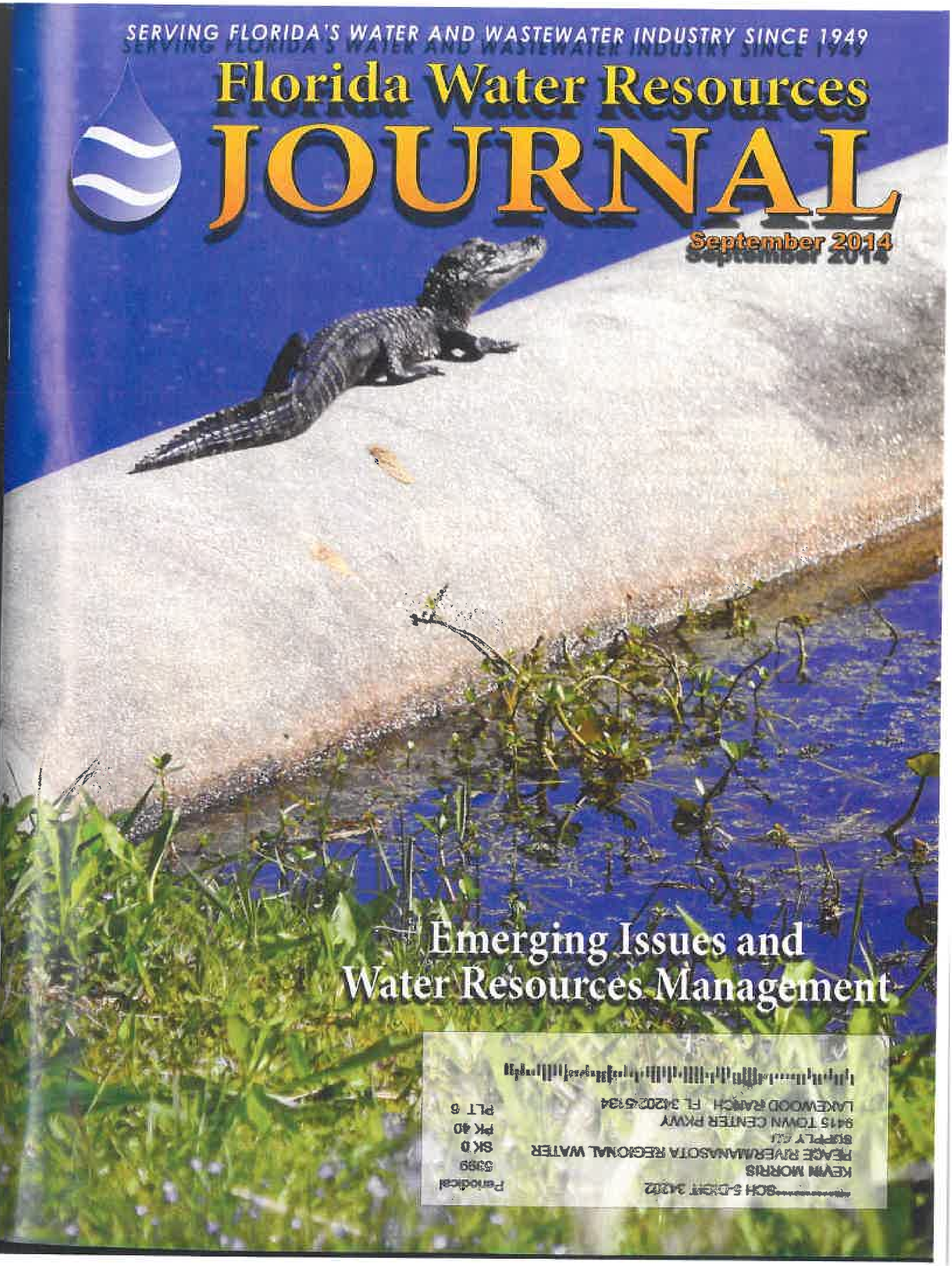

Emerging Issues and Water Resources Management

Developing a Surface Water Resiliency Model for the 21st Century

Kevin Morris, Mike Coates, and Mike Heyl

There is emerging recognition that issues such as sea level change and climate variability must be considered as a part of integrated water resource planning. Water managers often face decisions in which the ramifications of their actions may not be fully understood until further in the future. Issues such as growth, deteriorating infrastructure, or regulatory mandates often dictate a timetable for decisions that compel leaders to make prudent and timely decisions in spite of uncertainty and risk. Decision tools that provide the ability to assess the impact of sea level change and climate variability on water supplies help quantify the risk profile of a utility's asset portfolio over time. This capability is crucial in ensuring that optimal strategic choices are made in water supply planning.

This article summarizes development of the Peace River Operations Platform Assessment Tool (PRO-PAT), a powerful decision tool that combines the ability to explore the benefit of future capital projects, determine the effectiveness of operational strategies, and assess potential impacts of climatic shifts on system reliability into one unified model.

The Peace River Facility

The Peace River Facility was originally constructed in the late 1970s, and after a number of expansion projects over the past 15 years, now consists of two offstream raw water storage reservoirs totaling 6.5 bil gal (BG) of capacity, 21 Aquifer Storage and Recovery (ASR) wells, and a 48-mil-gal-per-day (mgd) capacity conventional surface water treatment plant. Figure 1 presents an aerial photograph of these facilities. The Peace River Facility is located on the northern bank of the Peace River approximately 11 river mi east of Interstate75 and almost 40 river mi from the Gulf of Mexico at Boca Grande Pass. Although it would take over an hour by car to reach the beach at Boca Grande from the river intake, the river intake pump station is located just above sea level. The water level at the river intake is greatly influenced by tide, and during dry periods, this can lead to elevated salinity levels in the river.

The Authority's water use permit (WUP) allows withdrawals from the river based upon a moving, seasonal percentage of the collective flow measured from three U.S. Geological Survey (USGS) stream flow gauges: the Peace River at Arcadia; Horse Creek, near Arcadia; and Joshua Creek, near Nocatee. The Authority's WUP prohibits diversion of any river water when the flow is less than 130 cu ft per second (cfs). This extremely protective provision prohibits river diversion when flows are naturally low as a measure to protect the complex downstream ecosystem in Charlotte Harbor. The Authority conducts extensive hydrobiological monitoring throughout the lower Peace River and Charlotte Harbor to collect data on the ecosystem. This program has yielded a good understanding of the flow-dependent nature of water quality in the river.

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Figure 1. The Peace River Facility With Reservoirs Looking West Over the Peace River

Climate Variability Within the Context of Water Supply Sustainability

The Earth has been in a constant state of change since its creation. Sea level in the past has been both higher and lower than present levels and temperatures, and rainfall patterns have historically varied as well. Anthropologists studying ancient cultures often point to climate variability as a likely factor in social collapse due to droughts and floods. Modern food storage techniques, global transportation networks, and sophisticated public works projects can support vast cities in barren, inhospitable landscapes. However, not too long ago, disruptions in agricultural production and/or water availability could quickly lead to food shortages, social unrest, and societal collapse as indigenous peoples perished or migrated where conditions for subsistence were more favorable.

Mankind has only been measuring the Earth's climate and weather patterns using modern scientific methods and technology for a very short representative period in the planet's history. Although glacial ice cores are helpful in quantifying conditions many thousands of years ago, the leap from understanding the past to being able to predict the future involves great uncertainty. Climate-prediction models are incredibly complex and there is vigorous debate concerning the role that anthropogenic activity plays in determining future climate conditions. Further complicating matters is political polarization of the climate change issue and powerful special interests that stand to profit handsomely from resulting policy directives and mandates.

Water managers may be well advised to steer clear of the highly polarized debate and simply ensure that their organizations are considering the most recent official government sea level and climate variability projections, and layer this guidance into their strategic planning frameworks. Climate variability is working its way into the public consciousness, fueled by media coverage of extreme weather events of the past decade, such as Hurricanes Katrina in New Orleans and Sandy in the Northeast. The loss of life and property damage from these storms provides visceral examples of the tragic risk that society faces because of the preference for coastal development. Unless corrective measures are taken, as sea level rises, the risk of flooding and inundation along the coastlines will increase.

Other current examples are the ongoing historic droughts in Texas and the Western United States, which have laid bare the inadequacy of public water supplies that previously had been thought sufficient. Historic flow records for many streams and rivers in the U.S. only date back between 50 and 100 years, which in the context of natural systems, is a very limited timeframe. An understanding of the variation in climate and how it affects the nation's water supply needs may be growing, but is far from complete and reinforces the wisdom in carefully considering climate-trend projections.

Projected Climate Variation Trends

The most definitive projections for future climate trends in the U.S. today are presented in the Third National Climate Assessment (NCA), produced in 2014 by the U.S. Global Change Research Program. This program is

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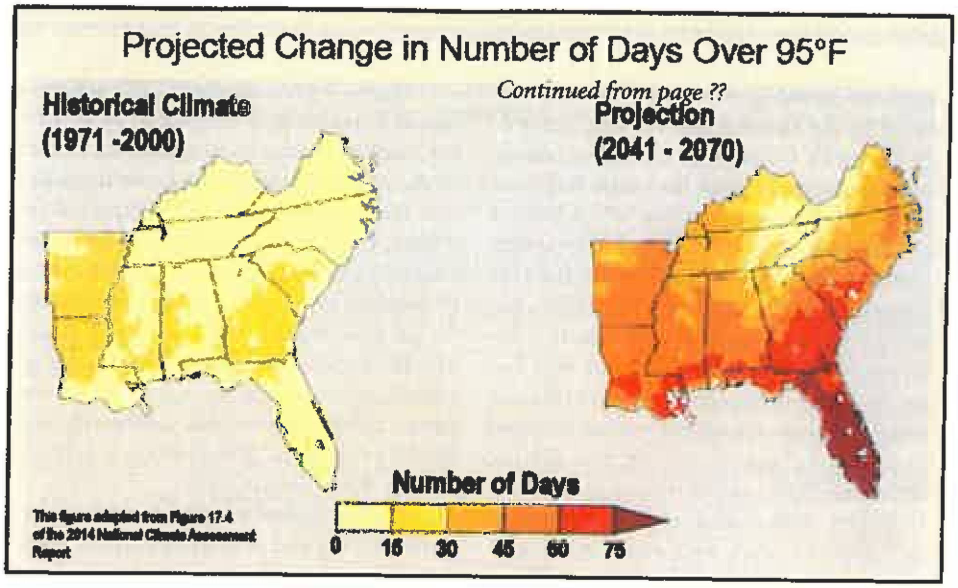

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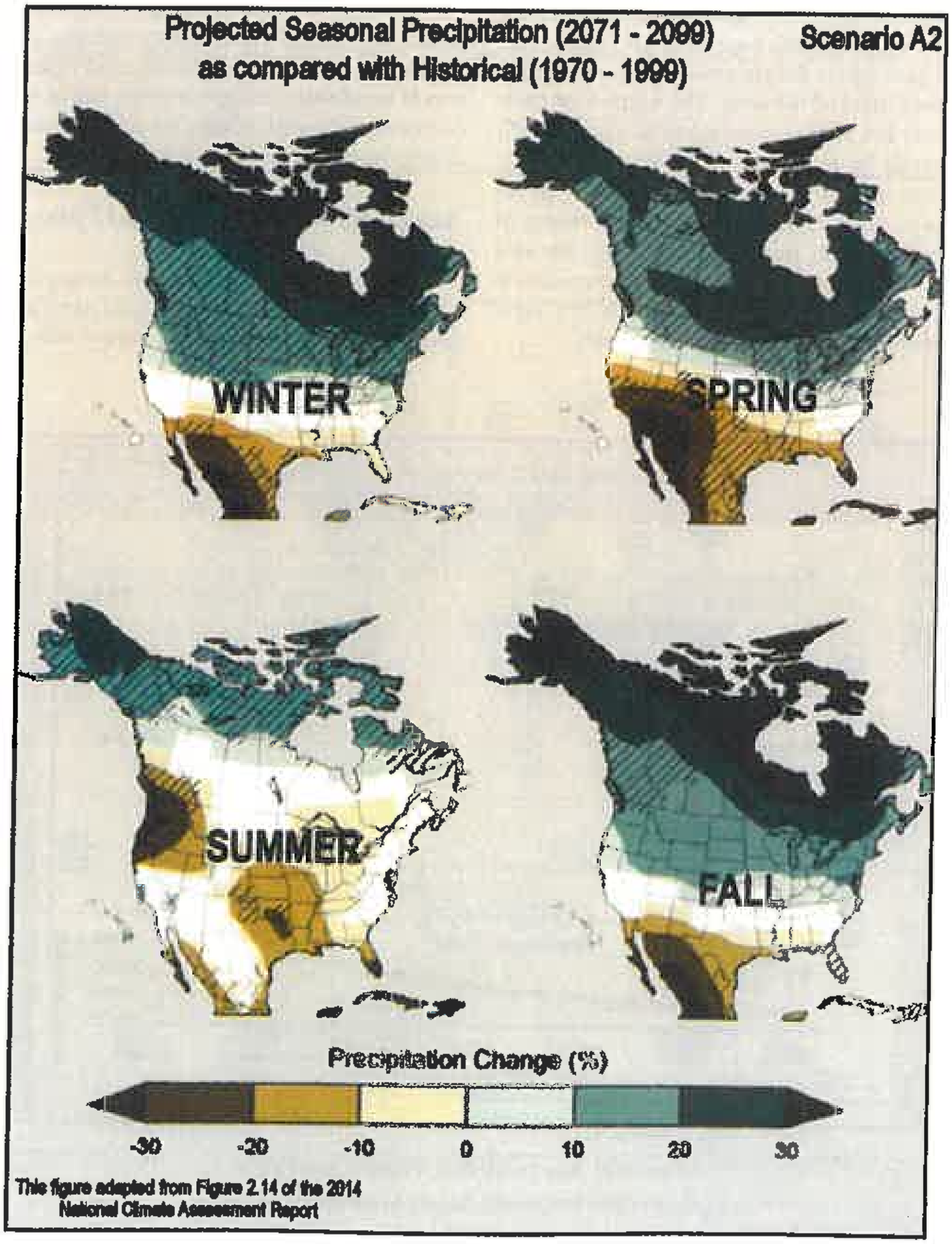
This figure adapted from Figure 17.4 of the 2014 National Climate Assessment Report

Figure 2. Projected Annual Hot Days in the Southeastern U.S. (from Third National Climate Assessment, 2014)



This figure adapted from Figure 2.14 of the 2014 National Climate Assessment Report

Figure 3. Projected Seasonal Precipitation Change for North America (from Third National Climate Assessment, 2014)

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steered by the National Science and Technology Council's Committee on Environment, Natural Resources, and Sustainability, and consists of the research arms of 13 federal agencies, including the National Aeronautics and Space Administration (NASA), the U.S. Environmental Protection Agency (EPA), the National Science Foundation, and the U.S. departments of Agriculture, Defense, and Energy. The NCA summarizes consensus climate projections from a regional perspective, and this article focuses on projections for the Southeastern U.S., and Florida in particular.

Figure 2 summarizes the number of "hot" days (i.e., days with a maximum temperature above 95°F) that the NCA report states may be expected for the 30-year period from 2041 to 2070, as compared with what was experienced for the 30-year period from 1971 to 2000. The figure reflects that, during the earlier period, there were less than 15 days a year where the temperature exceeded 95°F over most of the state. The number of these very hot days is expected to increase significantly by as many as 40 to 50 days per year over most of the Florida peninsula in the future. This could bring an expectation of higher water demand usage rates, elevated surface water impoundment evaporation rates, and an increased potential for algae blooms in raw water impoundments.

Figure 3 presents the NCA's consensus seasonal precipitation projections expected for the North American continent toward the end of the present century. The projections show that increased precipitation is expected over Alaska, Canada, and many of the northern states for winter, spring, and fall. However, the projections indicate less overall precipitation for all four seasons over the entire state of Florida. Spring and summer appear especially troubling for the southern part of the state, from Tampa to Melbourne southward, where 20–30 percent less precipitation is predicted during those periods.

The NCA also provides discussion about the frequency and severity of tropical storms, which are expected to increase in response to higher ocean temperatures. More intensive downpours could result in a greater proportion of total precipitation finding its way to runoff with less local recharge. River and stream flows could become more variable, reflecting increased storm intensity and higher runoff variability. Storage elements will likely become a more critical focus for surface water system sustainability in the future.

Sea Level: Past, Present, and Future

Scientists believe that sea level, during the peak of the last Ice Age in North America (about 22,000 years ago) was almost 400 ft lower than present-day levels. If sea level were 400 ft lower than it is now, the state of Florida would cover almost three times more surface area and would be more than 300 mi wide on an east-to-west line between Tampa and Melbourne. Sea level fluctuates mainly in response to global ice inventories and thermal expansion of ocean water. However, movements of the earth's crust also affect localized apparent sea level movement and can exacerbate or offset sea level rise. For example, parts of Louisiana are battling the combined effects of ground-level subsidence and sea level rise, with apparent sea level rise rates three times higher than Florida. On the other hand, in the Gulf of Alaska, as a result of Pacific plate subduction under North America, the ground surface is rising faster than sea level, so the effect is a localized apparent sea level decline.

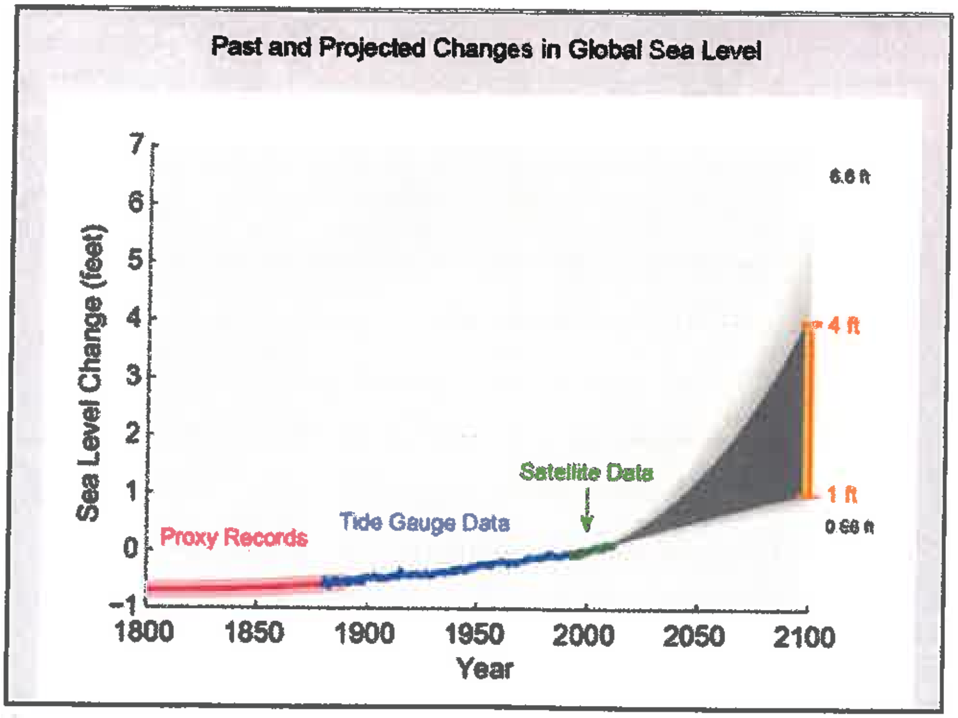

Figure 4. Sea Level: Past, Present, and Future (from Third National Climate Assessment, 2014)

Figure 4 from the NCA report shows that sea levels have risen about 8 in. over the past 200 years and are projected to continue to rise anywhere from 1 to 4 ft higher between now and 2100. Rising sea level creates a host of natural and societal concerns, including: seashore erosion, compression of transitional ecological buffers (dune systems and salt water marshes), heightened risk to people and property from storm surges and flooding, risk of salt water intrusion to groundwater supplies, and increased risk of salinity incursions up historically fresh rivers and streams.

Sea level rise and the potential for changing climate patterns are causing emerging concerns for water supply managers, especially in Florida, which is a peninsula surrounded by water. The Authority's intake structure, almost 40 river mi from the open waters of the Gulf of Mexico, is unprotected by salinity barriers as the river flows freely to tide. It is the flow of freshwater down the river and into Charlotte Harbor that pushes the ocean's salinity downstream. Clearly, sea level will impact this dynamic relationship as saline water pushes upstream. These impacts would be strongest at lower flow levels when the forcefulness of river flow is relatively weak. The challenge is quantifying this impact on river water quality.

Projecting River Water Quality Impacts from Sea Level Rise

Understandably, methodologies for projecting the impacts of sea level rise on water quality within river and estuarial systems are not well defined, since this is a relatively recent area of concern. The approach employed in this work was chosen because a USGS tide gauge located at the Authority's river intake pump station provided a relevant database of tide level and water quality data. Also, the Peace

River is still largely channelized in this portion of the drainage basin, and so as sea level rises, it is not projected to significantly spill out of its banks, which would radically alter the behavior of fresh and saline water interfaces.

Since the Peace River flows unobstructed to tide in Charlotte Harbor, salinity intrusion from tidal effects can spread back upriver a distance, depending upon variables such as tide, wind, and river flow conditions. As sea level rises, the tide-related effects on river salinity, as measured at the current river intake, are expected to increase. The river gauge station installed on the Authority's river intake structure in 2009 provides a useful record of tide level and conductivity data (conductivity here is used as a surrogate for salinity). These data have been analyzed in an effort to model tide-level-related water quality relationships based upon the fundamental underlying presumption that historic tidal effects would emulate the impact on water quality, which would be expected from a commensurate rise in sea level at the same relative river flow.

The data were modeled using statistical analysis systems (SAS) to develop the water quality prediction model that is summarized here in general form. This model focused on the low river flow range between about 100 and 500 cfs. It is within this relatively weak flow regime where sea level rise would be found to have the greatest impact on water quality.

$$C = b_{\propto} + (b_1 \times Flow1) + (b_2 \times Flow2) + (b_3 \times Stage) + (b_4 \times (Stage/Flow))$$

where:

C = conductivity (uS/cm)

$\beta_{\propto}$ = specific intercept

β_1 = "short-term" flow slopes (linear and/or nonlinear)

β_2 = "long-term" flow slopes (linear and/or nonlinear)

β_3 = gage height specific slope

β_4 = gage height/flow interaction specific slope

The model was then applied to vertical sea level rise projections from the 2013 Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). Forced convergence was applied at high river flows in recognition that the model was developed for use between 100 and 500 cfs, and that at extreme flows, the saline interface would be pushed well downstream in all scenarios. The model results and scenarios were then consolidated into a baseline condition reflective of current conditions, and then five progressively

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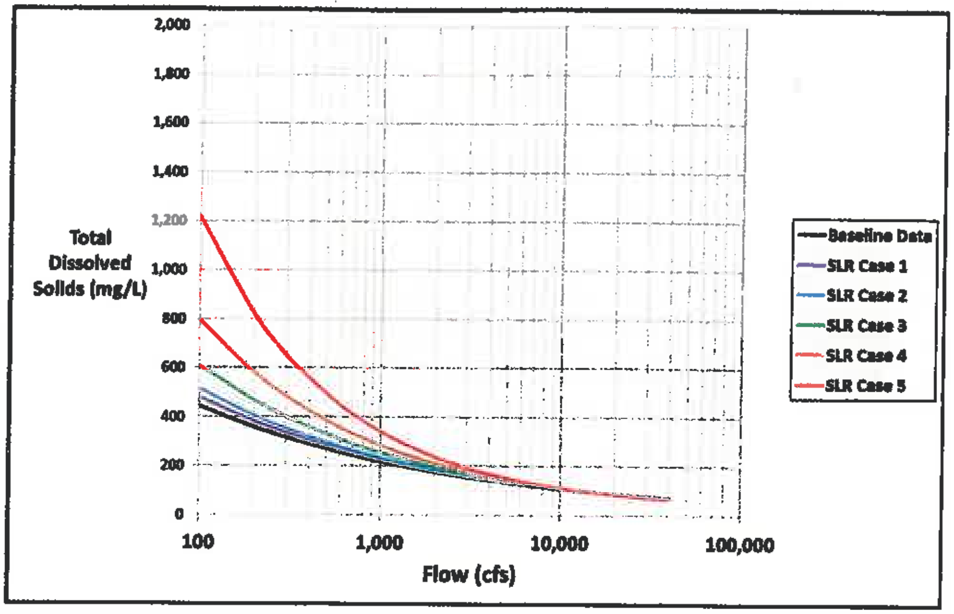

Figure 5. Sea Level Rise Scenarios for Total Dissolved Solids as a Function of River Flow

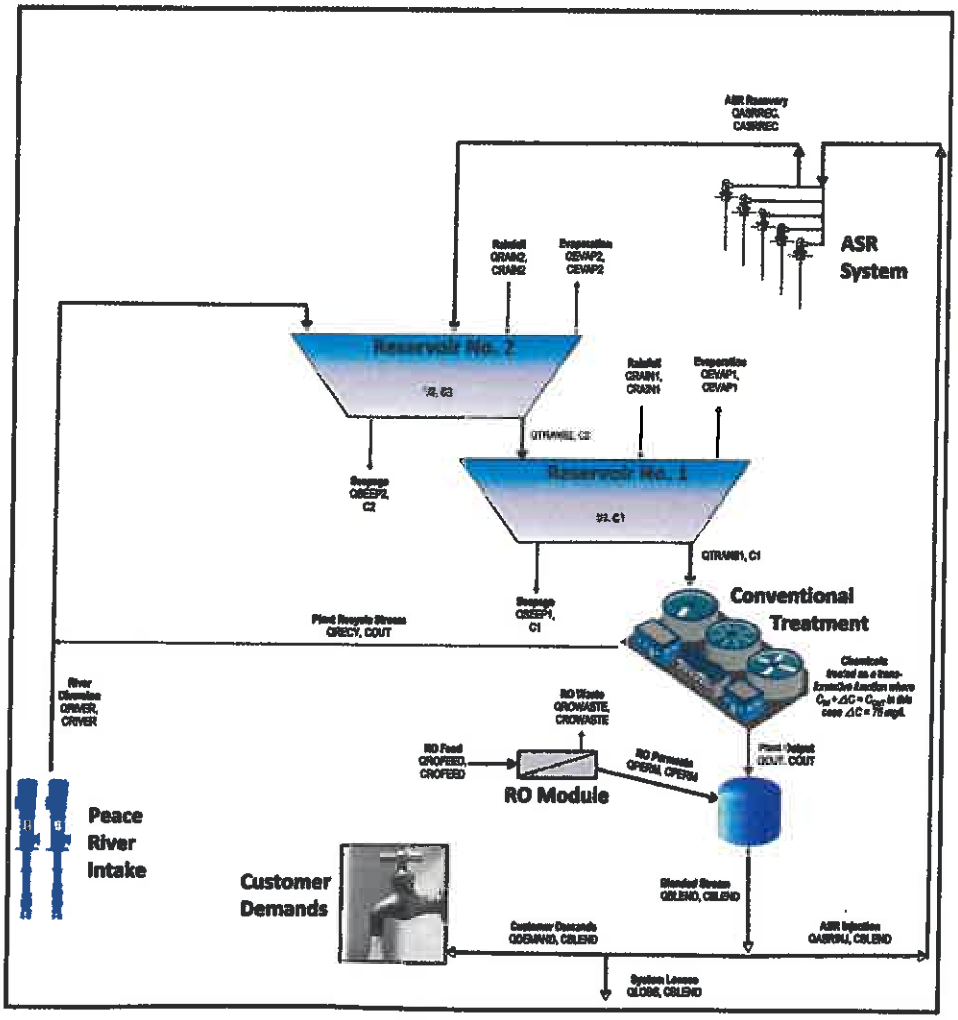

Figure 6. Mass Balance Schematic for 2 Reservoir System

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worse sea level rise (SLR) scenarios. The worst-case scenario, SLR Case 5, correlates roughly to the IPCC's worse-case scenario of 25 in. of sea level rise by 2075. The resulting river flow-salinity relationships developed for these cases are illustrated in Figure 5. The conversion from measures of conductivity to total dissolved solids (TDS) was based upon a ratio of 0.69 micro mhos per cm for each 1 mg per liter of TDS.

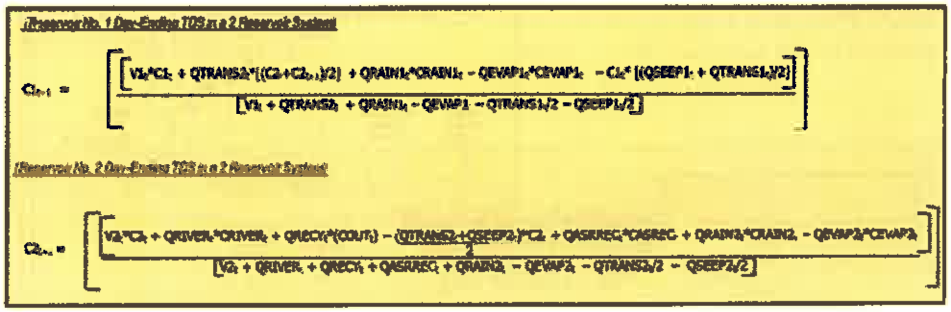
Peace River Operations Platform Assessment Tool Model

The Authority has employed reliability modeling as a decision tool since its inception and reliability projections have guided each major capital expansion project. Early reliability models focused solely on ensuring that there would be adequate reserves available to meet customer demands without regard to quality. Authority reliability models have grown successively more sophisticated as computer hardware and software has evolved and as programmer skill has increased. Also importantly, over time, additional operational data have been gathered that refine the understanding of ASR system performance, which can be quite a challenging application to model.

Driven by the desire to understand possible impacts from a sustainability perspective, Authority staff developed PRO-PAT. This model is developed in a Microsoft Excel 2010 workbook, with most content on a single worksheet using about 600 columns and 16,000 rows. The resulting workbook is approximately 200 megabytes in size and contains over 200 charts and 4,000 statistics. A deterministic model, PRO-PAT is based on river flow and rainfall for the 38-year period of record from 1975 to 2013. The model is fundamentally tied to the conservation of mass for both solvent (water) and solute—in this case, TDS. The TDS is a secondary drinking water parameter, which means it is associated with aesthetic rather than health concerns. The TDS has a maximum contaminant limit of 500 mg/L and has historically been the parameter of greatest concern for the Authority. However, a similar approach could be used for other conservative, nonreactive solutes of interest such as sodium, chloride, or sulfate.

Figure 6 presents an illustration of the Peace River Facility system, with the existing two raw water reservoirs and a supplemental groundwater-based reverse osmosis (RO) module. In this configuration, ASR recovery water is directed back to Reservoir No. 2. The figure identifies all of the major variables (flow, volume, and concentration) between each functional block. These variables are used to derive the mass balance equations for the system, which ultimately predict the finished water TDS on a daily basis. Since this is a daily model, it is helpful to use nomenclature such as A_t and A_{t+1} to represent the value of variable A at the beginning of the day and end of the day, respectively.

Quantity reliability is determined by considering the number of days during which the system failed to fully meet the specified level of demands, divided by the total number of days in the model sequence. Quality reliability is determined by the number of days during which the finished water failed to meet the 500 mg/L secondary drinking water limit for TDS or failed to meet demands, divided by the total number of days in the model sequence. Quality reliability will always be lower than quantity reliability under the logic that the quality of the water doesn't matter if there is not enough to meet customer needs.



(Reservoir No. 1 Day-Ending TDS in a 2 Reservoir System)

$$C1_{t+1} = \left[\frac{\left[V1_t{*}C1_t + QTRANS2_t{*}[(C2_t+C2_{t+1})/2] + QRAIN1_t{*}CRAIN1_t - QEVAP1_t{*}CEVAP1_t - C1_t{*}[(QSEEP1_t + QTRANS1_t)/2]\right]}{[V1_t + QTRANS2_t + QRAIN1_t - QEVAP1 - QTRANS1_t/2 - QSEEP1_t/2]}\right]$$

(Reservoir No. 2 Day-Ending TDS in a 2 Reservoir System)

$$C2_{t+1} = \left[\frac{\left[V2_t{*}C2_t + QRIVER_t{*}CRIVER_t + QRECY_t{*}(COUT_t) - \frac{(QTRANS2_t+QSEEP2_t)}{2}{*}C2_t + QASRREC_t{*}CASREC + QRAIN2_t{*}CRAIN2_t - QEVAP2_t{*}CEVAP2_t\right]}{[V2_t + QRIVER_t + QRECY_t + QASRREC_t + QRAIN2_t - QEVAP2_t - QTRANS2_t/2 - QSEEP2_t/2]}\right]$$

Figure 7. Sample of Mass Balance Equations for 2 Reservoir System

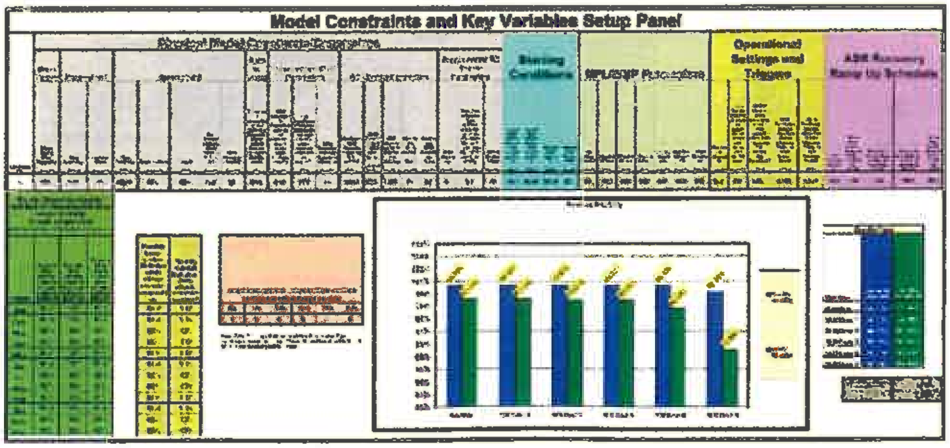


Figure 8. User Interface Design

PRO-PAT Model Input Variables

The model includes 109 variables, of which 49 are operational variables and the remaining 60 are focused on climate variability. Each model run is actually six runs in parallel: the baseline condition, as well as the five progressively more severe SLR scenarios. The period used to drive the model is the 38-year period from 1975 to 2013. This includes the daily historic flow records for Joshua Creek, Horse Creek, and the Peace River, as well as the local monthly rainfall and evaporation records for the same period. The monthly rainfall data come from the composite seven-county average for Charlotte, DeSoto, Hardee, Highlands, Manatee, Polk, and Sarasota counties. The evaporation data come from a station located at Lake Okeechobee, operated by the South Florida Water Management District, and has been adjusted from pan evaporation data to simulate lake evaporation. Monthly rainfall and evaporation totals are divided by the number of days per month to derive a daily rate for the model.

The 49 operational variables include basic dimensional parameters such as river diversion pump capacity and reservoir volume, as well as the programmed starting conditions for each. The operational variables also include codification of the operational constructs used to govern how the facilities are managed. For example, there are trigger set points that tell the model when to initiate ASR recovery and recharge at what flow rate. Another way of looking at operational constructs is to view them as the "rules of the game." The process of discussing and evaluating each of these decision points is enlightening. It is critical to understand the triggers for when and why an organization makes its water-resource decisions in order to be able to then code them as logical statements in a model.

The 60 climate-related variables provide the modeler the ability to vary historic rainfall, evaporation, and stream flow for the three streams that comprise the aggregate flow basis for the WUP on a monthly basis. These variables are set up as a forcing function and are originally set to 100 percent, but can be changed upward or downward as appropriate to evaluate contemplated effects of wetter or drier conditions.

Mass Balance Equations

In this model, each reservoir is assumed to be fully mixed and homogenous. The model moves sequentially through the subsystems, solving for volume and flow, beginning with customer demands and working back towards the river. Once all flows and volumes are known, concentrations can then be calculated, but this time starting at the river and working back towards the customer. Mass balance relationships expressed over time are like a journey: where it ends depends on where it starts, how fast the travel is, and for how long. The basic TDS continuity equation for an open system with conservation of mass can be expressed as:

$$TDS_{t+1} = \frac{TDS_t {*} V_t \pm \sum_{i}^{n} Q_i TDS_i}{V_t \pm \sum_{i}^{n} Q_i}$$

where:

TDS_t = concentration at the beginning of the day

TDS_{t+1} = concentration at the end of the day

V_t = system volume at the beginning of the day

Q_i = any flow into or out of the system *(flows into the system would have a positive sign, whereas flows out of the system would have a negative sign)*

TDS_i = *the concentration of any flow Qi which crosses the system boundary and is always positive in sign*

n = the number of streams crossing the system boundary

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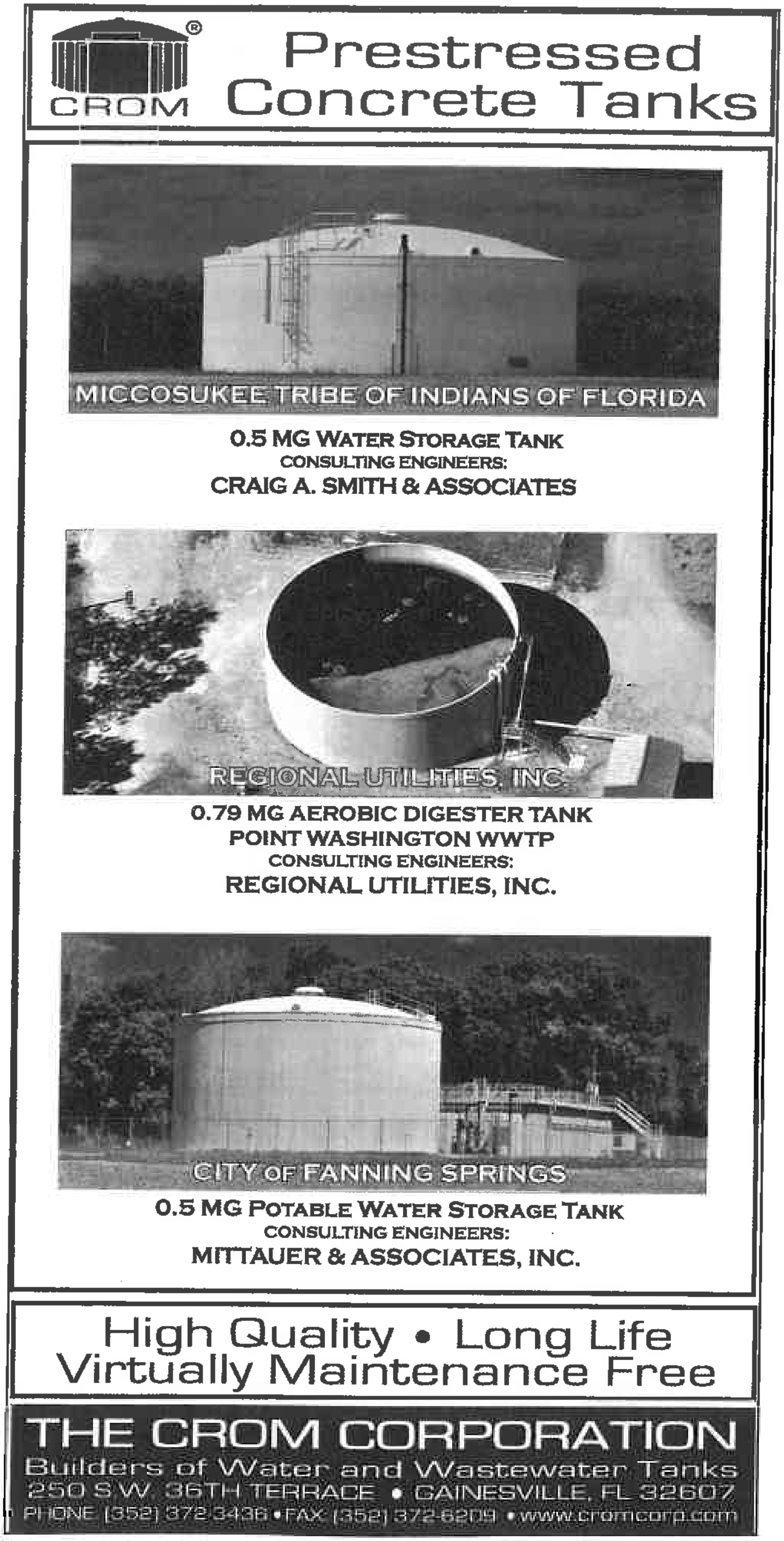

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The lengthy expression development steps for the concentration at the end of the day for Reservoirs No. 1 and No. 2 are not included here for brevity. However, the final equations for the concentration at the end of the day for Reservoirs No. 1 and 2, respectively, $C1_{t+1}$ and $C2_{t+1}$ are presented in Figure 7.

Time Well Spent: Design of the User Interface

This moderately complex model has over 100 input variables and each model run yields six simultaneous scenario results. Simply put, the workspace, at nearly 600 columns wide and 16,000 rows long, is enormous. A great amount of time was devoted to planning the workspace and developing an interface panel that included all variables, as well as the summary results for the six scenarios. The resulting interface panel is 42 columns wide by 24 rows high and includes a graph of the quantity and quality reliability findings for the model run. The design makes it possible for modelers to never have to need to leave this interface panel unless they wish to scroll down or over to explore some of the individual embedded graphs or statistics. Figure 8 includes a screenshot of the PRO-PAT main user interface panel. A well-designed interface panel allows modelers to focus their energy and attention on scenario analysis, reduces wasted time, and cuts down on mistakes.

Model Runs With and Without Temperature, Rainfall, or Stream Flow Variation

Figure 9 presents reliability results for the base condition model run without temperature, rainfall, or stream flow variation; note that sea level rise is not projected to have any impact at all on quantity reliability through SLR 4. For the worst-case SLR scenario, SLR Case 5, quantity reliability was still greater than 98 percent. The quality reliability values tell a slightly different story; the effects of sea level rise are evident with each scenario falling to as low as 84.8 percent for SLR Case 5, but again, this is the worst-case scenario for over 50 years into the future, assuming no improvements are implemented.

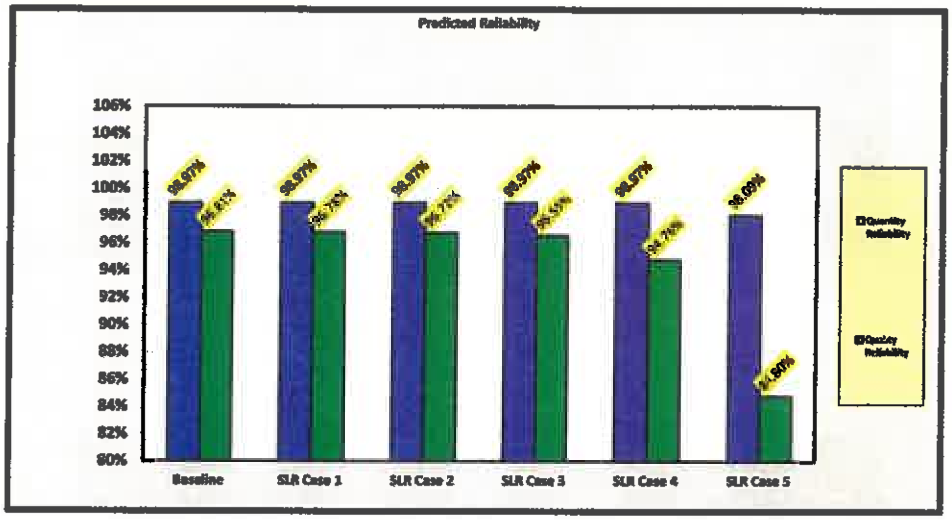

Figure 9. Base Model Results Without Temperature, Rainfall, and Stream Flow Variation

Next, the climate forcing function variables are used to reduce stream flow and rainfall from April–September, from 100 percent down to 85 percent. The evaporation was also increased due to the projected hotter conditions from 100 to 115 percent over the same timeframe. Figure 10 presents reliability results for the base condition model run with these climate variation changes. Overall quantity reliability values have fallen by about 0.4 percent across the full range of SLR scenarios as compared with the model run prior to implementing the climate variability changes. Quality reliability was also reduced as compared with the value presented in the prior section, and ranged from 0.5 percent less reliability for the baseline condition to 3 percent lower for the worse-case sea level rise scenario at just 81.7 percent. This exercise demonstrates how the model can be used to quickly assess the effects of climate variability.

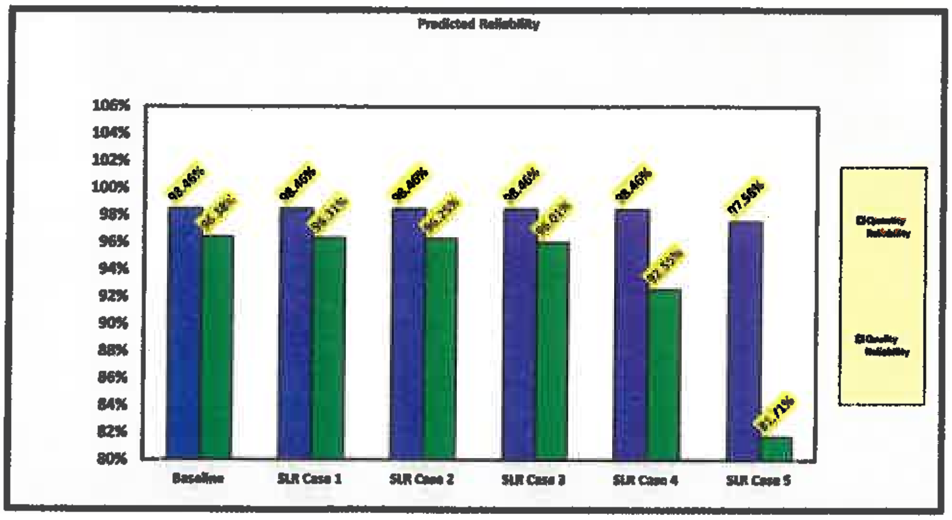

Figure 10. Base Model With Temperature, Rainfall, and Stream Flow Variation

Exploring Adaptation Management Strategies

Adaptation management strategies are approaches that can help a utility overcome the effects of future sea level rise and climate variability. Two strategies are explored here: adding more raw water storage, and adding a supplemental source of supply. Figure 11 presents the reliability results obtained if 6 BG of additional raw water storage were added, along with an additional 80 mgd of river diversion pumping capability. This strategy results in 100 percent quantity reliability for all scenarios, even the worst-case SLR Case 5 scenario. Quality reliability is also much improved, increasing for all scenarios and almost reaching 94 percent for the worst-case SLR Case 5 scenario.

Now, instead of adding additional raw water storage, consider a strategy consisting of adding a supplemental source of supply in the form of a brackish groundwater RO source. Using the PRO-PAT model an RO module can be programmed with a maximum productive capacity of 6 mgd running at a base production rate of 3.5 mgd. The model includes a trigger point for when the RO module should be compelled to ramp up from the base production rate to maximum capacity. This strategy has a double benefit: it not only offsets a supply need from surface waters, but also beneficially dilutes the finished water leaving the facility.

That ramp-up trigger was set at 4 BG of raw water storage for these runs. Figure 12 presents the results. One of the first observations is that the run achieved 100 percent quantity reliability for all except the worst-case SLR Case 5 scenario, which had 99.46 percent reliability, although that is still very good. The quality reliability values were generally a bit lower than the storage-based example, with the exception of the worst-case SLR Case 5 scenario where there was an almost 2 percent improvement in reliability over the storage-based solution.

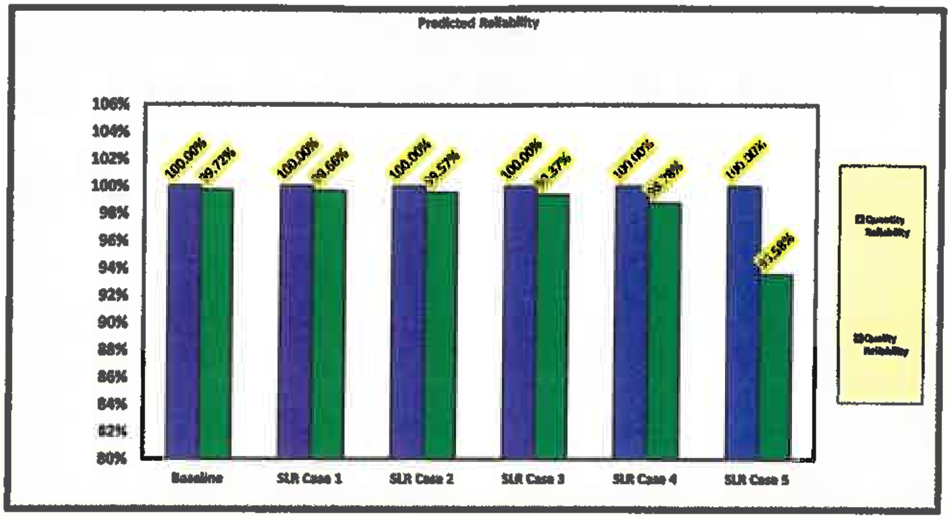

Figure 11. Adaptation Management Strategy 1: Additional Raw Water Storage

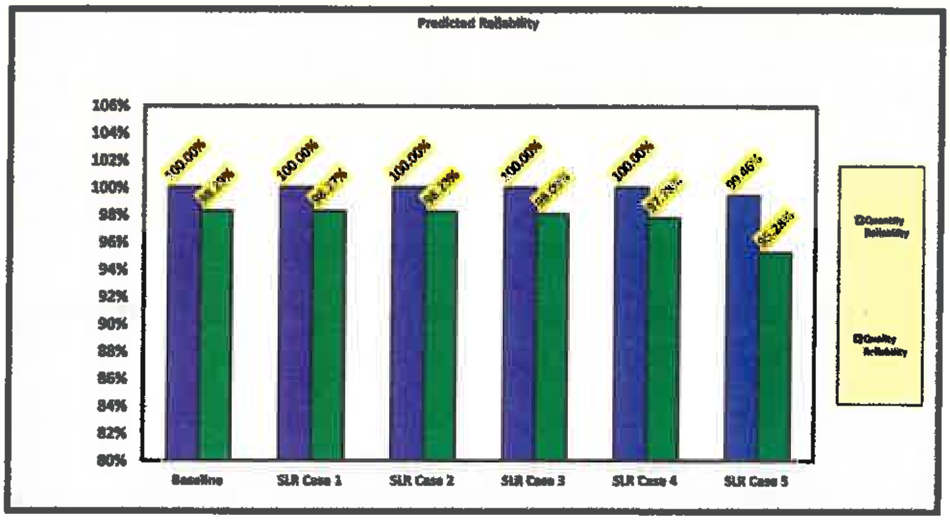

Figure 12. Adaptation Management Strategy 2: A Brackish Water Reverse Osmosis Module

Conclusions

Water supply managers face significant challenges from future climate-related uncertainties. Decision tools can play an important supporting role in placing prospective risks into comparative context, as well as helping guide industry leaders in making difficult decisions. Climate-prediction science is complex and evolving, and the ultimate role that anthropogenic factors play in determining future climate conditions is still being debated. However, few would dispute that the Earth has always been in a state of change, and recent extreme weather events support the hypothesis that there is a great deal more variability in weather and climate patterns than previously understood.

In the future, projections show that Florida can expect hotter, drier conditions than in the past. Storms and rainfall events are likely to be more extreme and sea level is projected to rise from 1 to 4 ft above present levels by 2100. The Authority's development of the PRO-PAT toolset gives it the ability to gauge its water supply asset portfolio within a sustainability context and gives it a tool with which to explore selected adaptation management strategies. The utility's storage-dependent design concept is well suited to future climate variability, and little impact from sea level rise is projected before 2075. The model demonstrates the viability of adaptive management strategies, such as adding raw water storage or a supplemental groundwater source. Either of these strategies would handily provide the Authority the capability to overcome any loss in reliability as a result of climate variation and sea level rise in this century.

The PRO-PAT model only generates reliability data and cannot replace the value of a robust engineering cost-benefit analysis of alternatives or the value of a diversified portfolio of sources in furthering water supply system resiliency. There are many other plausible adaptation management strategies, such as relocating the river intake pumps further upstream; however, the space allowed here does not afford the opportunity for an exhaustive review of all possible alternatives. Finally, climate variability projections are not a precise science and projections are constantly being revised and updated. Utilities need to be prepared to update and calibrate their decision tools frequently to reflect the latest techniques and projections to ensure that their strategic planning framework reflects the latest guidance.

Acknowledgements

The origins of the PRO-PAT model can be traced to early work by staff at the Southwest Florida Water Management District who developed a spreadsheet-driven flow engine that converted historic stream flow into available diversion quantities and projected Authority usage of the resource, including interplay of ASR operations. Ralph Montgomery with Atkins provided valuable guidance on sea level rise scenarios and the potential for water quality changes. Pete Larkin and Ryan Messer of CH2M HILL, and Mark McNeal of ASRUS Inc., provided guidance on ASR recovery water quality modeling. Lastly, the authors would like to recognize the many scientists, professional educators, utility representatives, and government agency participants with the Florida Water and Climate Alliance (www.floridawca.org) for their support in furthering the knowledge base in this important area. ◆