A Roadmap to Modeling a Source Water System

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Located in southwest Florida, Lee County Utilities (LCU) provides potable water services to approximately 89,000 accounts held by close to 300,000 customers residing within a 205-sq-mi region. As shown in Figure 1, this expansive domain is organized into the following four service areas that are served by their respective water treatment plants (WTPs):

- North Lee County service area - Served by North Lee County WTP
- Olga service area - Served by Olga WTP
- Pinewoods service area - Served by Pinewoods WTP
- Corkscrew/Green Meadows service area - Served by Corkscrew WTP and Green Meadows WTP

The LCU has consistently practiced master-planning efforts and prioritized capital improvement plan (CIP) projects to ensure that its customers have an uninterrupted and reliable water supply at all times. These preparatory efforts are particularly important to LCU's four service areas, given the diversity of their land and water use, as well as the distinct characteristics in this region's topography. For instance, as shown in Figure 1, the north service area is separated from the other areas by the 67-mi-long Caloosahatchee River. This means that, were this service area's single WTP to experience an unexpected interruption or failure, the service area would rely on finished water being relayed across the river, which could cause a potential bottleneck in the system.

With the intent to proactively plan for such failure scenarios, identify and address other similar vulnerable points in its system, and prepare for any supply deficiencies that may compromise its level of service, LCU decided to comprehensively evaluate the condition and reliability of its potable water system.

As a first step, and with engineering assistance from Carollo Engineers Inc. (Carollo), LCU projected its system's maximum monthly average demands (MMADs) and annual average demands (AADs) from years 2018 through 2040. The demand information was then used to develop a detailed, holistic planning model of LCU's infrastructure and operations. Finally, the planning model was run against various scenarios to identify limitations at LCU's system and identify corresponding capital improvement projects and/or response procedures to address such limitations.

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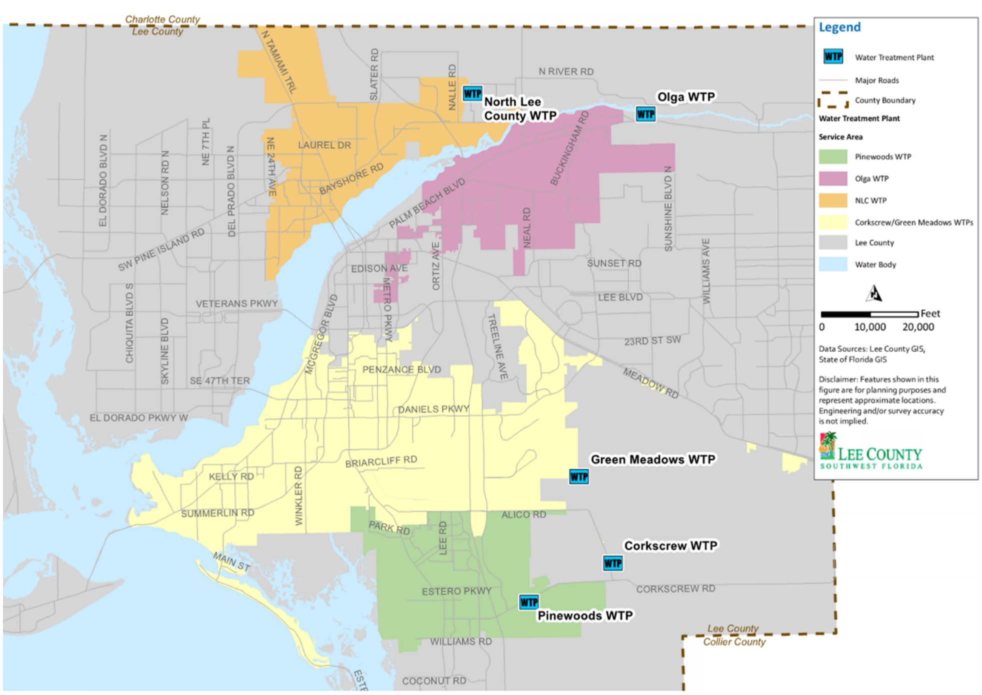

Figure 1. Lee County Utilities Potable Water Service Areas

The development and use of this model exemplify how proactive and preventative planning efforts assist utilities to understand what types of failures are expected within their water systems and when they are most likely to occur, down to the specific trigger years. Such knowledge not only lowers the risks of similar failure events, but also equips utilities with more than just reactive responses to events that might have otherwise been prevented or anticipated.

This article presents a step-by-step examination of the progressive measures that LCU and Carollo took to develop a progressive planning model of this potable water system, including a systematic description of how the team created the model, entered inputs, selected and ran specific failure scenarios, and assessed its results to pinpoint system-specific recommendations.

Utilities may use each step to begin creating or optimizing their own water system models and evaluate their resiliency to ensure that customer demands are reliably met—now and into the future.

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Model Development

The LCU planning model was initially developed as a component of its source water supply, redundancy, operations, and management plan. Current and future supply capacities were modeled using a simulation, optimization, and decision-support tool, Blue Plan-it® (BPI), developed by Carollo. Built on an ExtendSim® platform, BPI effectively incorporates a utility's growth projections, capacity analyses, permitted supply quantities, assets and their redundancy, and overall health into a customized model.

The LCU currently draws water from two sources: groundwater and surface water. The majority of demand is supplied by groundwater from three regional aquifers, which is pumped by 121 production wells and five aquifer storage and recovery (ASR) wells. The remainder is supplied by surface water from the Caloosahatchee River (C-43 canal). Five WTPs located in LCU's four service areas, which are linked by several interconnects, treat this source water.

To model finished water distribution, the four service areas were grouped into the following three distribution zones:

- North – North Lee County and Olga service areas
- South – Corkscrew/Green Meadows service area
- Pinewoods – Pinewoods service area

The service areas were grouped into these three zones to more accurately reflect the system. Demand projections for each distribution zone were entered into the model on an annual average and maximum month basis.

Given this information, the BPI model centered on the following five major components:

- Water sources: Water table aquifer, Sandstone aquifer, Lower Hawthorn aquifer, and C-43 canal.
- Wellfields: North Lee County, Corkscrew, Green Meadows, and Pinewoods wellfields.
- WTPs: North Lee County WTP, Olga WTP, Corkscrew WTP, Green Meadows WTP, and Pinewoods WTP.
- Interconnects:
  - Flow between the North and South distribution zones.
  - Flow between the South and Pinewoods distribution zones.
- Overall distribution system:
  - Production quantities and demand per distribution zone.
  - Gap analysis of each distribution zone's components.

Water Sources

Source water withdrawal for potable water production at LCU's WTP facilities is authorized by the South Florida Water Management District (SFWMD) water use permits (WUPs) 36-00003-W, 36-00152-W, and 36-00122-W. These WUPs dictate the maximum volume of water that LCU may withdraw from each of the three aquifers and the C-43 canal on a maximum month and annual basis. Green Meadows, Corkscrew, and Olga WTPs also have a combined allocation limit.

These allocations were all programmed into the model, assuming that the WUP allocations will not change with future permit renewals. Table 1 summarizes the permitted source allocations.

Table 1. Water Use Permit Allocation Summary

Facility	Source	Monthly Allocation Limit (MG)	Annual Allocation Limit (MG)
Corkscrew(1)	Surficial Aquifer	182.4	1,684
	Sandstone Aquifer	243.2	2,245
	Upper Floridan Aquifer	87.6	808
Green Meadows(1)	Water Table Aquifer	127.68	1,179
	Sandstone Aquifer	176.3	1,628
	Upper Florida Aquifer	474.2	4,378
Olga(1)	C-43	152	1,615.6
Combined Allocation(1)	Corkscrew, Green Meadows, and Olga sources	1,355	12,508
North Lee County(2)	Lower Hawthorn	592.9	5,886
Pinewoods(3)	Water Table Aquifer	69.9	676.5
	Sandstone Aquifer	22.5	217.8
	Lower Hawthorn Aquifer	176.0	1,791.4
	Combined Allocation	268.43	2,685.76

Notes:
(1) WUP 36-00003-W issued June 15, 2011, expires June 15, 2031.
(2) WUP 36-00152-W issued August 20, 2012, expires August 20, 2032.
(3) WUP 36-00122-W issued Dec. 1, 2014, expires Dec. 1, 2034.

Wellfields

Under the WUPs, each of LCU's wells has a specified capacity set according to the pump flow rate in gal per minute (gpm). Programmed data and user inputs (e.g., production rates and operational status) for each well in the North Lee County, Green Meadows, Corkscrew, and Pinewoods wellfields were determined using flow rates specified in the WUPs, relevant wellfield operating plans, and physical wellfield inspections. The WUP-outlined pump capacities were only modified in the model if they deviated from operating production rates recommended by a wellfield operating plan.

As is typical with most utilities, information available for each of LCU's pumps varied, depending on the data and materials available for each wellfield. That is, some wellfields had more detailed operational information regarding, for instance, how pumping capacities vary depending on monthly and annual limits, while others lacked specific information that may have been learned or acquired through actual operations and experience. The LCU operators filled much of these data gaps. This exemplifies that strong and consistent recordkeeping and management go hand-in-hand with effective modeling efforts.

Ultimately, the BPI model was programmed with the following inputs:

- Capacity of each well.
- Total number of wells.
- Number of duty wells (i.e., the number of operational wells) per water source.
- Number of duty wells per well usage type:
  - Existing – Well is installed.
  - Proposed – Well is permitted, but not installed nor operational.
  - Primary – Indicates well is regularly used.
  - Secondary – Indicates well is irregularly used (e.g., production well that is rotated).
  - Standby – Well used for special circumstances (e.g., emergencies).

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The inputs are allowed to be modified at any time by the user. If a well is no longer operational or operates at a higher or lower capacity, these updates can be easily changed; however, this model focused primarily on demand quantities and, as such, the quantities pumped from each of LCU's wells. For this reason, source water quality was considered a secondary focus and only factored into the model when a specific quality issue was found to affect the water quantity withdrawn, treated, or distributed, or considered as part of a wellfield operating plan. Overall, LCU's source water results in finished water that consistently meets primary and secondary drinking water regulations.

North Lee County Wellfield

The North Lee County wellfield currently has 17 production wells. The LCU is currently constructing 12 additional production wells, for a total of 29 wells. Of the 17 existing wells, three are not operating due to water quality issues caused primarily by high-chloride concentrations and are typically not run in the model. Overall, high-chloride concentrations limit the withdrawal in the North Lee County wellfield.

For future scenarios, model inputs were adjusted to include the 12 new wells, where usage breaks down as four new wells to restore the wellfield's production capacity and provide redundancy for the 11.6 mil gal per day (mgd) North Lee County WTP, and eight additional new wells to provide additional supply for North Lee County WTP's planned expansion to provide an additional 5-mgd permeate capacity.

Green Meadows Wellfield

The Green Meadows wellfield has a total of 75 production wells. Of these wells, 24 are existing and 40 are proposed. One abandoned well was not included in the model.

Well production capacities used in the model were taken from this wellfield's most recent operating plan, which clarified that eight of the 24 currently active wells have different pumping capacities, depending on monthly and annual limits. As such, these eight wells were modeled to operate at 900 gpm, each on a maximum monthly basis, and at 500 gpm each on an annual average basis.

Corkscrew Wellfield

The Corkscrew wellfield has 55 production wells and five ASR wells.

According to the 2018 and 2013 operating plans for this wellfield, it's recommended that adjacent production wells within two groups of wells not be operated simultaneously. For this reason, the label "half available" is indicated in the model next to the two existing primary wells and 12 existing secondary wells drawing from the surficial aquifer to remind the user that no more than half the wells should be online in any scenario. Thus, the user should not input more than half the number of total wells as duty wells for those two groups. This same label was included for the two Upper Floridan wells, as only one of the two wells withdrawing from that aquifer should operate at a time due to the elevated salinity of this source.

Meanwhile, the five ASR wells are operated during periods of high demand from January to May. In the model, ASR wells were inputted to turn on during the maximum month scenario, which, historically, occurs during this time frame.

Pinewoods Wellfield

The Pinewoods Wellfield has 15 production wells, all of which were included in the model alongside the option to add up to 12 proposed wells for future scenarios.

For the three proposed water table aquifer wells, all three wells are technically considered existing in the WUP, but they are identified as proposed in the model because, although the wells are constructed, they lack the equipment to be operational. The same reasoning was applied to the two Sandstone wells. Additionally, two other wells have historically produced a lower-than-expected yield, and for that reason, are not currently used by the county. In the model, both of these wells are set to "offline."

Water Treatment Plants

As previously explained, LCU's four service areas were broken up into three distribution zones: (1) the North zone, containing North Lee County WTP and Olga WTP, (2) the South zone, containing Corkscrew WTP and Green Meadows WTP, and (3) the Pinewoods zone, containing Pinewoods WTP.

The following capacities and operational assumptions for LCU's five WTPs were programmed into the model:

- North Lee County WTP – This WTP currently has four reverse osmosis (RO) trains with a total existing permeate capacity of 10 mgd, and its current design includes 1.6 mgd of bypass flow, for a total facility capacity of 11.6 mgd. In 2020, the facility began the process to expand with an additional 5-mgd permeate capacity. The model assumed 80 percent recovery through the RO process.
- Olga WTP – This WTP's design treatment capacity is 5 mgd. The model assumed

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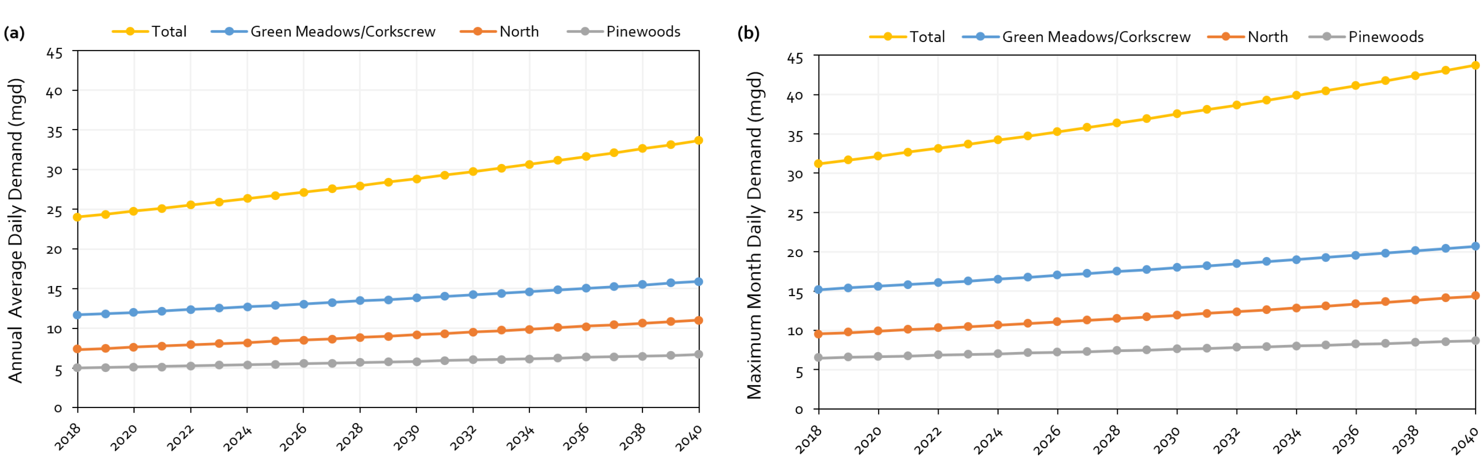

Figure 2. Annual Average Daily Demand (a) and Maximum Month Daily Demand (b) Projections

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5 percent treatment losses through the plant's physical-chemical treatment process, which primarily consists of powdered activated carbon (PAC), aeration, coagulation, dual-media filtration, and granular activated carbon (GAC) adsorption.

- Green Meadows WTP – This facility has three treatment processes: (1) water from the surficial aquifer is treated using ion exchange, (2) water from the Upper Floridan aquifer is treated using RO membranes, and (3) water from the Sandstone aquifer is bypassed and blended into the finished water. The model assumed 5 percent losses for treated water during the ion exchange process and an 85 percent recovery for RO. The WTP has a 14-mgd finished water capacity.
- Corkscrew WTP – Currently the largest of the five WTPs in possible finished water production, this facility is rated for a 15-mgd capacity, and all water supplied to it is treated using lime softening. The model assumed 5 percent treatment losses through the process.
- Pinewoods WTP – This facility includes nanofiltration (NF) membrane softening and RO. The three NF trains have a permeate capacity of 2.3 mgd, while RO treatment has a permeate capacity of 2.5 mgd, plus up to 0.5 mgd of raw water bypass. The model assumed 75 percent recovery for NF and 80 percent recovery for RO.

Prioritization of source water and treatment could be modified in the BPI model. For instance, in the North distribution zone, production from North Lee County WTP has priority over Olga WTP since the WTP's groundwater supply is more reliable than the withdrawal requirements of pulling from a surface water (C-43 canal). This means that the model was set up to use all of the supply and treatment capacity from North Lee County WTP and to only use Olga WTP's supply if additional water is needed to meet demand. This capability allows the user to prioritize production of the plants located in the north and south treatment areas, allowing the user to do a sensitivity analysis of these types of prioritization decisions, if desired.

Interconnects

In the event that demands cannot be met by a WTP located in a particular distribution zone, two interconnects within the LCU system join the three distribution zones. Note that LCU's system has several interconnects throughout its service areas; however, these interconnects were simplified to two interconnects in the model so as to see the overall finished water transfers between the distribution zones. The first interconnect relays treated water between the North and South zones, while the second interconnect allows water to flow between the South and Pinewoods zones. The model allows for any amount of treated water to flow through each interconnect, though the model issues an alert when that volume exceeds 3 mgd.

Overall Distribution System

With the source water system's components created and inputted into the model, current and projected customer demands were evaluated against the finished water capacities that LCU can produce and distribute. A per capita finished water demand factor of 100 gal per capita per day (gpcd) was used with population projections to projected AADs until 2040. Meanwhile, maximum month demands used a peaking factor of 1.3. Figure 2a and 2b shows the annual average and maximum month water demands for each distribution zone, respectively.

The demand projections were then evaluated against the capacities of the five WTPs to produce finished water on an annual average and maximum month basis, as shown, respectively, in Figure 3a and 3b.

The production rates indicated for each facility were established according to either treatment capacity (i.e., design capacity) or production capacity based on supply allocation (i.e., permitted source water allocation including treatment losses), whichever was more limiting. This approach allowed each facility's most conservative production rates to be incorporated into the model.

For instance, Green Meadows WTP has a design treatment capacity of 16 mgd, but can only operate at a maximum capacity of 14 mgd given the associated wellfield's capacity. Meanwhile, the Olga WTP's permitted maximum month and annual allocation limits are 5 mgd and 4.4 mgd, respectively; however, when treatment losses (assumed

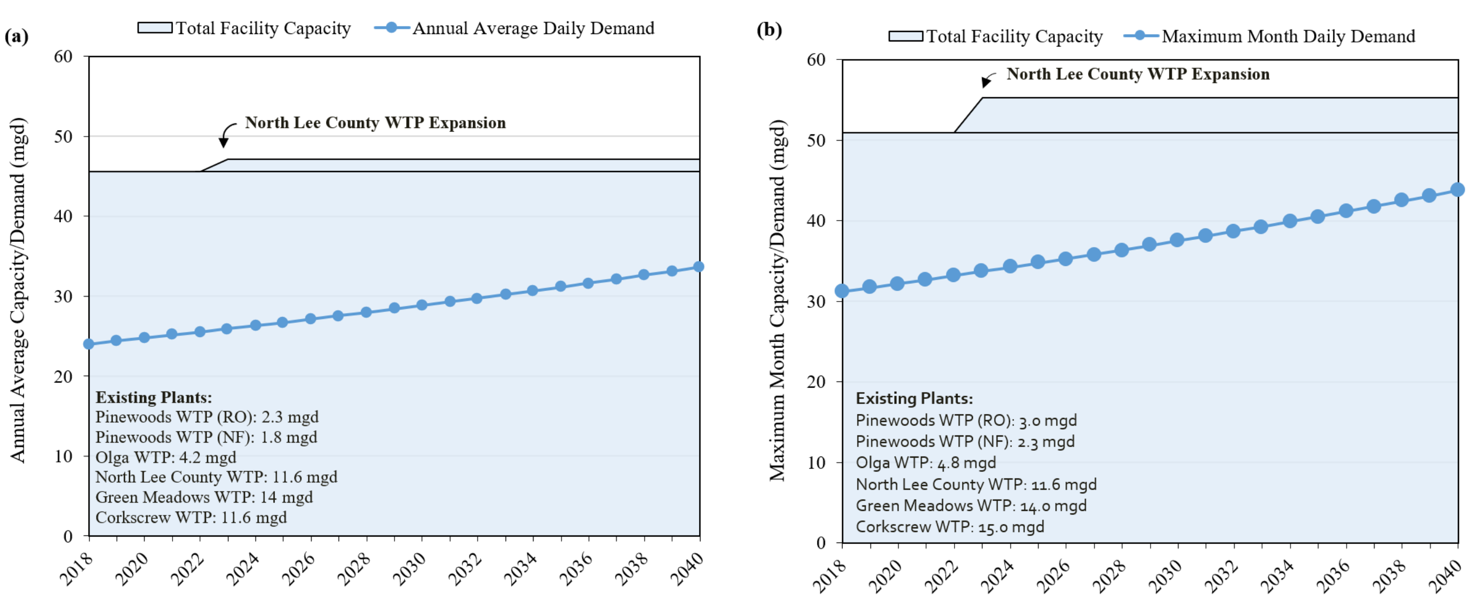

Figure 3. Permitted Supply and Demand on an (a) Annual Average and (b) Maximum Month Basis

to be 5 percent) are included, finished water production rates reduce to 4.8 mgd under maximum month conditions and 4.2 mgd under annual average conditions.

Overall, the existing supply and treatment facilities, plus the planned expansions to the North Lee County wellfield and WTP, have enough capacity to meet LCU's annual average and maximum month demand projections through 2040.

Gap Analysis

The model was next used to perform gap analyses comparing the various capacities within a particular distribution zone to its demand. Figure 4 embodies these analyses under current and future maximum month scenarios. Maximum month scenarios were run in the model because, when compared against annual average scenarios, maximum month scenarios are more limiting when considering a water supply facility's abilities to meet demand.

In each graph, the permitted supply allocation (indicated by the "Permit" bar), operational wellfield capacity (indicated by the "Wells" bar), and water treatment capacities (indicated by the "WTP" bar) are shown in relation to the demand. The red lines highlight the lowest and highest values, thus illustrating the "gap."

The results of the gap analysis were used to identify supply and production deficiencies in each distribution zone and recommend appropriate remediating actions. Figure 5 shows an overview of the BPI model's dashboard. Once the user verifies the inputs in the model, it can be run, and this dashboard provides a high-level overview of the production and demands. Any bottlenecks in the system are shown as yellow triangles. A bottleneck indicates where in the system capacities were reached. Green checks and red Xs are shown to indicate whether demands are met and if interconnect transfers exceed 3 mgd, respectively.

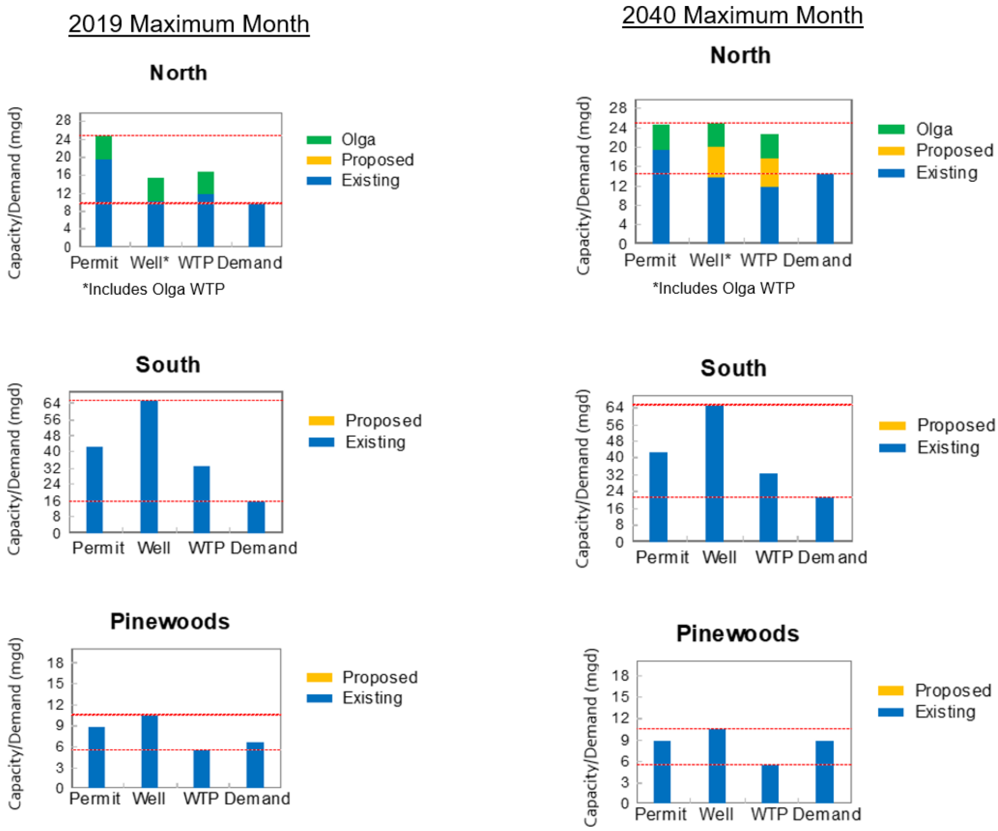

Figure 4. Current (2019) and Future (2040) Maximum Month Gap Analyses

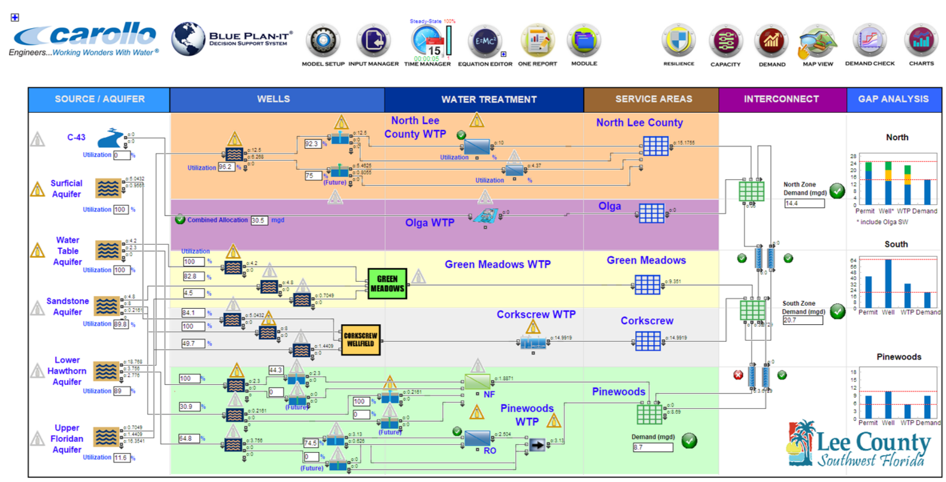

Figure 5. Lee County Utilities Source Water Model Overview Dashboard

North Distribution Zone

The gap analysis revealed that, although the existing North Lee County wellfield's permitted supply is adequate, the wellfield assets operated using the current operating plan do not produce enough water for the North Lee County WTP to operate at its full capacity. When also considering recovery losses through the treatment process, the WTP alone cannot meet the current maximum month demand in the North zone; however, with Olga WTP online, demand can be satisfied with some available redundancy of permitted allocation and supply assets.

On an annual average basis, the North Lee County WTP alone can meet current demand in the north zone; however, this requires 100 percent utilization of wellfield assets. Therefore, when a well is offline for maintenance, or as demand increases before the wellfield expansion project is placed into service, the North zone's demand must be met through another source (e.g., Olga WTP or transfer of water from the South distribution zone).

By 2040, the expanded North Lee County wellfield, plant and permitted allocations, will be sufficient to meet demand, and Olga WTP will serve to provide additional redundancy in the North zone. To achieve this result, the model assumed that the wellfield's existing

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wells will be operated in 2040 using current flow rates, and a total of 12 new wells will be constructed, each with a production rate of 725 gpm. These production flow rates are substantially higher than those of existing operations, which are currently 300 to 550 gpm per well.

If well production decreases over time or the water quality in the wells degrades, such that the proposed wells also need to be operated at lower flow rates, then the North Lee County wellfield may not have sufficient redundancy in the future. Thus, LCU was recommended to further assess the potential to operate the newer wells at reduced flow rates with its wellfield/hydrogeologic consultant, and then plan accordingly to maintain the required redundancy.

South Distribution Zone

The gap analysis showed that water supply and treatment from Green Meadows and Corkscrew WTPs are adequate to not only meet the South distribution zone's current and future demands, but also supplement demands in other zones. The large gaps between the "Well" and "Demand" bars in Figure 4 indicate good redundancy of assets at the Corkscrew and Green Meadows wellfield.

With that being said, two potential improvements were identified for the Green Meadows service area:

- *Adding another Upper Floridan well* – The Green Meadows wellfield currently has eight Upper Floridan wells that feed Green Meadows WTP's RO system. While the LCU proactively protects its RO systems' membranes from fouling, the production rates from these wells can vary depending on the results of the silt density index (SDI) testing performed at each well site. To run the WTP's RO system at its full capacity, all eight Upper Floridan wells must be running, meaning that the RO system cannot currently operate at its full capacity due to the SDI limitation. To fully utilize this system, LCU was recommended to construct additional Upper Floridan wells.
- *Adding another deep injection well* – Neither Green Meadows WTP's RO, nor its ion exchange systems, can be operated without a deep injection well, and with only one deep injection well, the plant has no redundancy for concentrate disposal. Therefore, LCU was recommended to install another deep injection well at the WTP.

Table 2. Individual Failure Events

ID	Failure Description	Probability Score (Near-Term)	Probability Score (Long-Term)
F01	Corkscrew WTP Offline due to Finished Water Line Break to Booster PS	8	5
F02	Corkscrew WTP Offline due to PLC failure	NA(1)	3
F03	Green Meadows WTP One Deep Injection Well out of Service	3	NA(2)
F04	Green Meadows Low Production on Floridan Wells	7	NA(3)
F05	Green Meadows Power Failure to Wells due to Hurricane/Disaster	3	3
F06	North Lee County WTP Offline due to Unplanned Outage	6	6
F07	North Lee County Water Quality Issues/Reduced Production	10	1
F08	North Lee County WTP Mechanical Failure due to Raw Water Main Break	5	NA(4)
F09	Pinewoods WTP Offline	2	2
F10	Olga WTP Offline due to Algae Bloom	10	10
F11	Olga WTP Offline due to TDS > 500 mg/L	2	8
F12	Olga WTP Offline due to Finished Water Main Break	1	1
F13	Olga WTP offline due to Residuals Handling Limitation	7	2
F14	Distribution Issue (unable to Transfer Water North)	5	NA(5)
F15	Distribution issue (unable to Transfer Water South)	9	5

Notes: 1 = lowest likelihood of an event occurring; 10 = highest likelihood of an event occurring.
(1) Scenario will be analyzed at 2040 MMAD only.
(2) CIP project to add second deep injection well scheduled for 2024 thus scenario not evaluated for long-term analysis (2040 MMAD).
(3) Assumes a CIP project to add Floridan wells (not yet slated in CIP); thus, scenario not evaluated for long-term.
(4) Existing project includes looping of raw water main or second raw pipeline into the plant thus scenario not evaluated for long-term.
(5) 30-in. transmission main in CIP for 2023 to resolve this issue thus scenario not evaluated for long-term.

Table 3. Combined Failure Scenarios

ID	Failure Description	Probability Score (Near-Term)	Probability Score (Long-Term)
CS1	Olga WTP Offline and North Lee County WTP Offline	6	6
CS2	Olga WTP Offline and North Lee County Reduced Wellfield Production	10	1
CS3	Olga WTP Offline and Corkscrew WTP Offline	8	6.5
CS4	Olga WTP Offline and Booster Pump Station Offline	5	NA(1)

Notes:
(1) 30-in. transmission main in CIP for 2023 to resolve this issue thus scenario not evaluated for long-term.

Pinewoods Distribution Zone

According to the gap analysis, additional water is needed to supplement production from Pinewoods WTP to meet its distribution zone's current and future maximum month demand. This insufficiency is caused by the WTP's permitted supply from the water table aquifer and the existing wells that withdraw water from the Sandstone aquifer, both of which limit production from the plant's NF trains, due to the WUP capacities allowed.

Demand in this zone can be met if water is transferred from the WTPs in the south distribution zone, which have more than enough water supply and treatment capacity to supplement Pinewoods WTP. It was decided by LCU to take this approach, and it was recommended to complete hydraulic modeling of its distribution system under existing and future conditions to ensure that sufficient flow can be transferred between the two zones, and that the distribution system is resilient to line breaks or other failure events.

Resiliency Evaluation

All modeling efforts culminated in a resiliency evaluation of LCU's potable water system. Once programmed with data detailing LCU's source and distribution systems, the BPI model was further updated and run to evaluate a total of 32 specific failure scenarios that may disrupt the utility's ability to meet demands and pinpoint specific improvements to prevent or prepare for scenarios that were found most likely to occur within the planning period.

Each scenario was assigned near-term (i.e.,

2020) and long-term (i.e., 2040) probability scores on a scale of 1, indicating the least likely scenario to occur, to 10, indicating the most likely scenario to occur. These scores were assigned according to LCU staff input, and this hands-on approach capitalized on staff's knowledge of the potable water system's past historical performance, decisions for planning certain CIP projects, and operational familiarity to capture a more-realistic picture of how "failure" would adversely affect the LCU system and the staff members who run it. These probability scores were used to prioritize the failure scenarios.

The LCU's system infrastructure was tested against the 25 individual failure scenarios shown in Table 2 and the seven combined failure scenarios shown in Table 3. Certain failure scenarios were not evaluated if CIP projects already planned by LCU, once implemented, will significantly minimize their likelihood of occurring.

The model showed that, of the 32 failures simulated, only nine scenarios may impede uninterrupted water supply to customers, either under the 2020 or 2040 MMAD. To aid LCU in prioritizing solutions to these failures, trigger years were determined for each scenario. Trigger years were calculated as the earliest year in which the failure scenario (at maximum-month demands) would result in the potable water demand exceeding the potable water system's supply.

In particular, the highest-ranking failure scenario, CS3 (Olga WTP and Corkscrew WTP offline) in Table 3, has a notably high probability of occurring in the near term. Multiple factors challenge the reliability of Olga WTP, which compounds the impact of other failures. This scenario considers a case in which both Olga and Corkscrew WTPs go offline under 2020 MMAD conditions; this failure is contingent upon the expansion efforts currently being undertaken at North Lee County WTP.

As identified by the North distribution zone's gap analysis, North Lee County WTP cannot currently meet the demands of this zone without 100 percent utilization of its wellfield assets or a supplement from Olga WTP. If the combined supply of these WTPs is not sufficient, flow can be transferred via an interconnect from the South distribution zone; however, if Corkscrew WTP, the plant producing the largest finished water volume in LCU's system, goes offline, not enough supply will be available for the transfer. As such, if both Olga WTP and Corkscrew WTP go offline before the North Lee County WTP expansion is complete, then LCU will not be able to reliably supply water to its customers in the North distribution zone.

Table 4. Summary of Failure Scenarios Not Meeting Demand

Rank	Probability	Description	Trigger Year	Potential Improvements
1	8	Olga and Corkscrew WTPs Offline at 2020 MMAD (Scenario CS3)	Present(1)	-
2	6.5	Olga and Corkscrew WTPs Offline at 2040 MMAD (Scenario CS3)	2029	Upgrade Corkscrew EI&C; Improve reliability of Olga
3	6	Olga and North Lee County WTPs Offline at 2040 MMAD (Scenario CS1)	2026	Improve reliability of NLC; Improve reliability of Olga
4	6	North Lee County WTP Offline (Unplanned Outage) at 2040 MMAD (Scenario F06)	2029	Improve reliability of NLC; Develop additional supply
5	5	Olga WTP and BPS Offline at 2020 MMAD (Scenario CS4)	Present(2)	Bypass AH; Evaluate 30'' transmission main
6	5	Distribution Issue (BPS Offline) at 2020 MMAD (Scenario F14)	2036(3)	Evaluate AH failure; Evaluate 30'' transmission main
7	5	Corkscrew WTP Offline (Finished Water Break to BPS) at 2040 MMAD (Scenario F01)	2037(3)	Emergency response/repair; Divert flows from Corkscrew to Pinewoods
8	3	Green Meadows WTP Offline (Power Failure to Wells) at 2040 MMAD (Scenario F05)	2035(3)	Upgrade Wellfield Power and/or Generator
9	3	Corkscrew WTP Offline (PLC Failure) at 2040 MMAD (Scenario F02)	2037(3)	Upgrade EI&C

Notes:
(1) Failure scenario will be corrected with NLC WTP expansion.
(2) Failure scenario is temporarily solved with NLC WTP expansion, then in 2026 this scenario will result in demands not being met.
(3) Failure scenario improvements should be investigated in LCU's subsequent water supply master plan.

With that being said, North Lee County WTP's expansion, which is planned to be complete in 2023, will reduce the risk of this failure scenario occurring since its 15-mgd permeate capacity will be enough to serve all of the North distribution system's needs. As such, no additional improvements were recommended for this failure scenario.

Table 4 lists the nine scenarios, which were prioritized by probability score and then trigger year, along with suggested potential improvements. It was recommended that scenarios with trigger years beyond 2030 (ranked 6 to 9 in Table 4) are evaluated as part of LCU's next water supply master plan to integrate projects that will increase system reliability.

Overall, the existing system can handle the majority of the failure scenarios without CIP project implementation or additional CIP projects, although executing already-planned projects will further increase its resiliency. Among the planned CIP projects, transmission mains are essential to meeting future demands, particularly those between the North and South distribution zones and between the South and Pinewoods distribution zones. The LCU is also prepared with emergency interconnects with neighboring utilities (Cape Coral, Bonita Springs, City of Fort Myers, etc.) to help meet demands during a failure.

Conclusions

The holistic planning model for LCU incorporated current (2020) and future (2040) AADs and MMADs, permitted source water allocations, existing and proposed water supply infrastructure, wellfield operations, and WTP capacities to reveal that, assuming normal operation, LCU's potable water system can meet current and future demands. When programmed with failure scenarios, the model exemplified the robustness of the system's resiliency, while allowing LCU and Carollo to prioritize, identify trigger years, and develop improvements to prevent the scenarios that were found to interrupt the reliable supply of water to customers.

Although LCU has always practiced a culture of proactivity and preparedness, this BPI model went the extra mile to pinpoint limitations and deficiencies, prepare for any failures that may occur in the near and long term, and further justify CIP projects that are already scheduled. As supply and demand continue to shift over the years and more upgrades are made to the system, LCU may continue updating and refining the model accordingly, remaining secure in the knowledge that it will always have a dependable and accurate decision-making tool at hand.