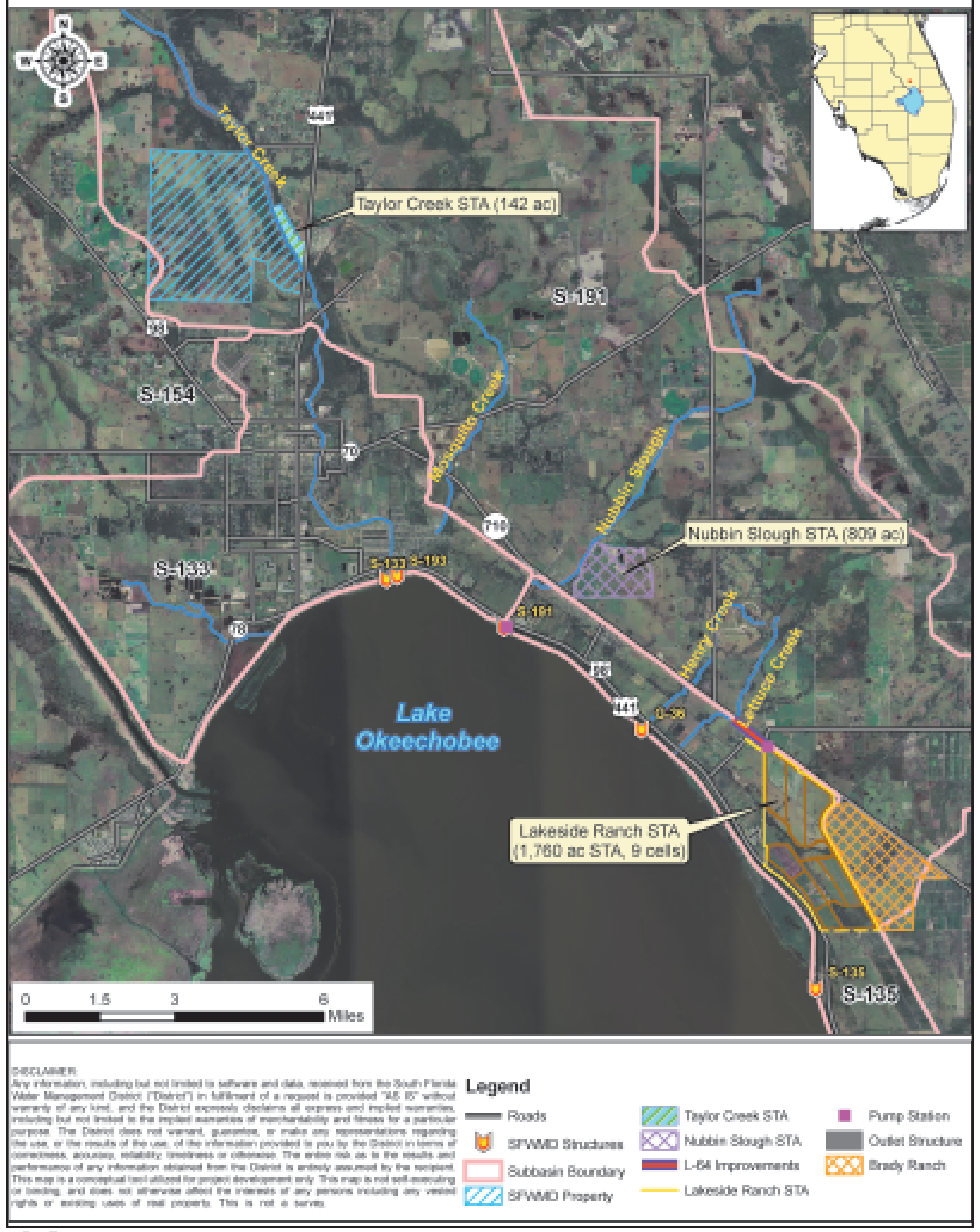
Fast-Tracking Lake Okeechobee Restoration: A Systems Evaluation for Optimizing Phosphorus Removal

Lena Rivera, Kirk Westphal, Michael Schmidt, and Mark Long

Lena Rivera P.E., is a senior water resources engineer with the Maitland office of the consulting, engineering, construction and operations firm CDM. Kirk Westphal, P.E., is a principal at CDM's headquarters in Cambridge, Massachusetts. Michael Schmidt, P.E., BCEE, is a vice president in the firm's Jacksonville office. Mark Long, P.E., is a project manager for the South Florida Water Management District's ACCELER8 program in West Palm Beach. This article was presented as a technical paper at the 2009 Florida Water Resources Conference.

Figure 1: Location of Proposed LOFT Projects (Preliminary Design Phase)



As part of the Lake Okeechobee & Estuary Recovery Plan, the Lake Okeechobee Fast Track (LOFT) Project is a group of facilities proposed by the South Florida Water Management District (SFWMD) to capture stormwater runoff north of Lake Okeechobee and treat it to remove total phosphorus (TP), which will help to improve the lake's water quality. This paper will focus on the systems modeling efforts provided by Camp Dresser & McKee, Inc. (CDM) to the district in support of the LOFT Project preliminary design phase, which includes two existing stormwater treatment areas (STAs), construction of a regional STA at Lakeside Ranch, and re-routing of stormwater flows from the S-135 and S-191 basins to the Lakeside Ranch STA.

As shown on Figure 1, the projects are to be located just north of Lake Okeechobee, in the Taylor Creek/Nubbin Slough Basin, which offers an optimal location for capturing and treating large amounts of phosphorus within state-owned properties located in the Northern Everglades area. An additional STA (Brady Ranch site) and a conceptual reservoir at the Lakeside site were further evaluated during this phase.

A dynamic system operations model using Systems Thinking Experimental Learning Laboratory with Animation (STELLA) software was used to incorporate information from more detailed models (*i.e.*, MODFLOW, WAM, and DMSTA2) and facilitate performance evaluations of the entire system, as shown on Figure 2. The STELLA model was used to test and validate conceptual configurations and operating rules to help guide the sizing of component elements, including storage and pump capacities and the locations of intake and discharge structures. Also, the model was used to test alternative operating protocols for the intercon-

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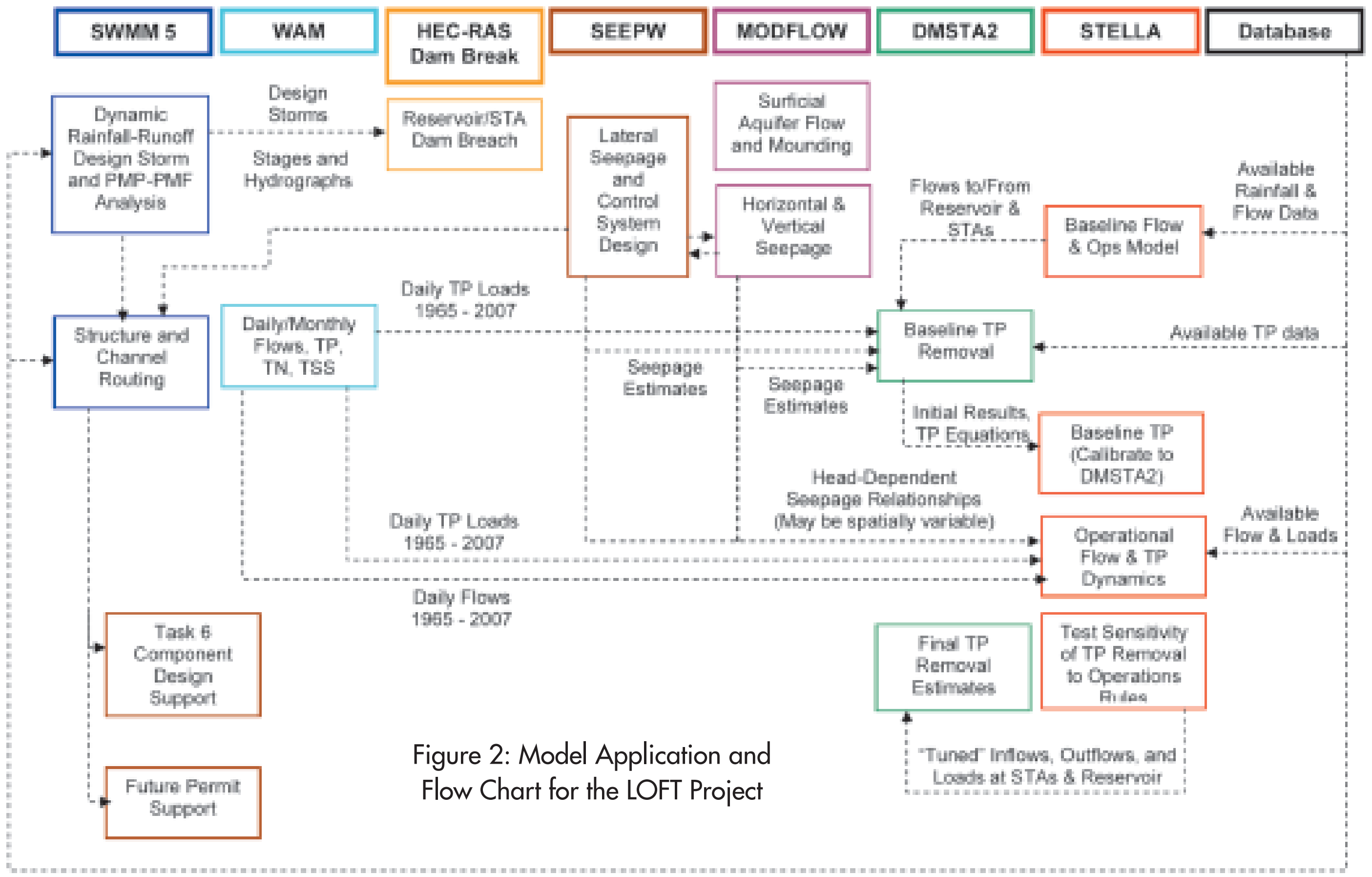

Figure 2: Model Application and Flow Chart for the LOFT Project

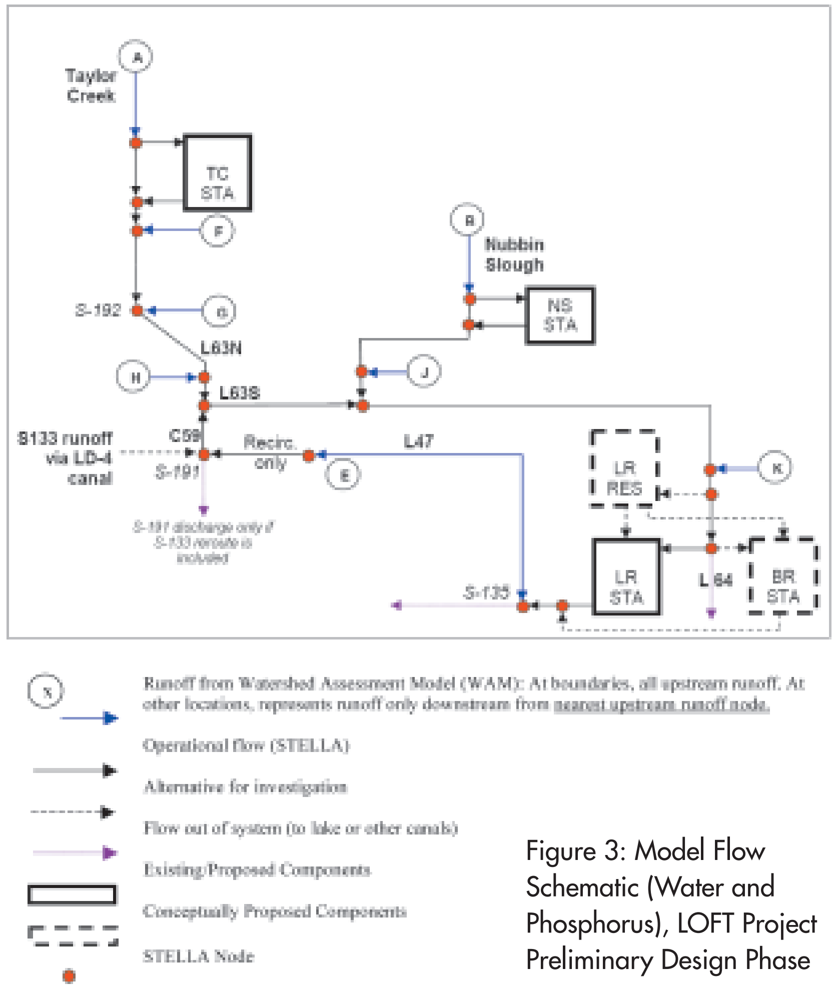

Figure 3: Model Flow Schematic (Water and Phosphorus), LOFT Project Preliminary Design Phase

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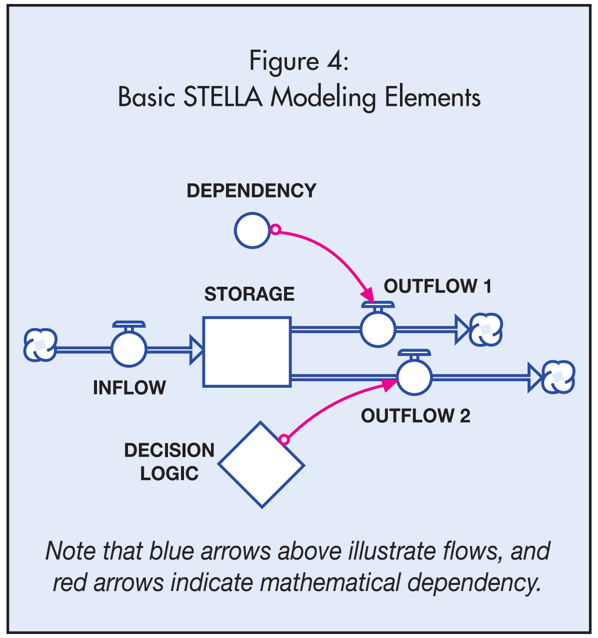
nected system and screen configuration alternatives prior to more detailed modeling with DMSTA2, a water-quality model that simulates hydrology and phosphorus dynamics of STAs.

For preliminary design of the LOFT Project, the model was used to evaluate the system-wide performance and water and TP budgets of the existing and proposed STAs in the S-135 and S-191 basins, including:

- Taylor Creek Critical Project STA (TCSTA, existing)
- Nubbin Slough Critical Project STA (NSSTA, existing)
- Lakeside Ranch STA (LRSTA, proposed)
- Brady Ranch STA (BRSTA, proposed)
- Lakeside Ranch Reservoir (LRRES, evaluated conceptually).

A schematic diagram of these interconnected elements is provided on Figure 3.

During the previous evaluation of the LOFT Project (Basis of Design phase), the model was used to evaluate alternative conceptual system configurations (using metrics of TP removal and duration of STA hydration), identify appropriate pump sizes, and determine which of the four originally proposed LOFT project alternatives should proceed to preliminary design (Taylor Creek Reservoir, Lakeside Ranch STA, re-routing of S-133 flow, and re-routing of S-154 flow). Of these, the model demonstrated that the Lakeside Ranch STA would be a most cost-effective component, although re-routing water from the S-133 basin was re-evaluated in the preliminary design phase to determine if its benefits were minimized by the Taylor Creek Reservoir,



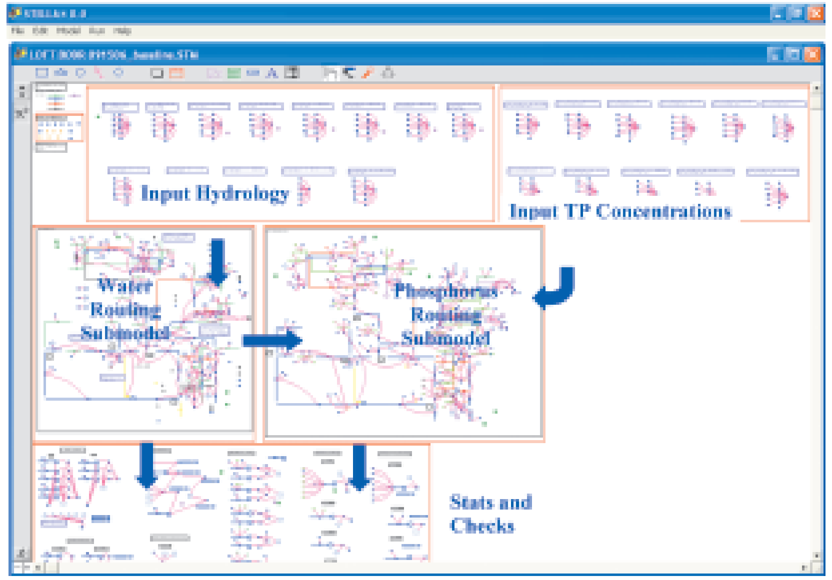


Figure 5: Model Structure and Information Flow

or if it really could not provide sufficient water at the right times (i.e., when the STA water levels were at or below the minimum operational depth) to be cost effective.

While it has been used to address numerous water resources planning issues in Florida and throughout the United States, the STELLA model was used specifically during the LOFT basis of design and preliminary design phases to integrate flow and water quality data from existing databases with output from other models, such as runoff, TP concentrations, groundwater seepage, and STA removal efficiency, and evaluate the dynamic interactions between the elements of the system (*e.g.*, coordination of flows and re-circulation). The internal mechanisms in the model focus on the mass balance calculation within storage elements and flow sequencing for multiple outflows from single storage elements. All other data, inter-element logic, and equations are entered by the model development team in the same way that such relationships are entered into a spreadsheet.

The advantages of the model are automatic checks to avoid inadvertent creation of water or mass at a storage element, the ability to prioritize multiple outflows from storage elements, and the ability to visualize the system and its complex interdependencies in a graphical platform. The user can sketch a system or combination of systems on a blank worksheet and study its dynamic response to input. The system is "drawn" as a combination of flow elements, storage elements, and variables on which dynamic values depend, as shown on Figure 4. The only hard-coded equation in the model is the continuity equation for conservation of mass (water and TP):

$$Storage_t = Storage_{t-1} + \sum Inflow_t - \sum Outflow_t$$

This tool includes a modeling worksheet

Table 1: Primary Configuration of LOFT Project Preliminary Design Scenarios

	LOFT Project Preliminary Design Scenario				
	PDR-1	PDR-2	PDR-3	PDR-4	PDR-5
Area of Lakeside Ranch STA, acres	2,400	2,400	1,800*	1,800*	2,400
Inclusion of Brady Ranch STA	No	Yes	No	Yes	Yes
Inclusion of Lakeside Ranch Reservoir	No	No	Yes	Yes	No
Inclusion of S-133 Re-routing	No	No	No	No	Yes

* Area of Lakeside Ranch STA reduced due to the presence of the Lakeside Ranch Reservoir

in which the interconnected system and all influencing factors are "drawn" schematically and mathematical equations are entered to compute mass balance across all system elements. For this LOFT preliminary design phase, the model was configured to function with a daily time interval for a 41-year period (1965-2007) and was used to:

- Evaluate water and TP budgets.
- Screen alternative system configurations for feasibility and effectiveness.
- Compare and contrast feasible alternatives with respect to design and operating parameters.
- Understand sensitivities in the system.
- Fine-tune system performance by adjusting its variables and operating rules to improve performance toward specific operational goals.

The screenshot shown on Figure 5 illustrates the macro-structure of the model, including the direction of information transfer.

The model was used to evaluate and compare a variety of alternative configurations of the Lakeside Ranch site, with each alternative defined by:

- Utilization of the available space (one STA, multiple STAs, and combined reservoir-STA)
- Storage footprints
- Operating (maximum, minimum, and average) depths in each storage and treatment element
- Pump capacities and ranges
- Operating rules
- Water conveyance configurations

Several combinations of these key characteristics were evaluated to determine the combinations that appeared most likely to remove phosphorus from the system effectively and reliably.

The four LOFT project components evaluated in the preliminary design phase included the Lakeside Ranch Reservoir (LRRES), Lakeside Ranch STA (LRSTA), Brady Ranch STA (BRSTA), and re-routing of the S-133 basin via the C-59 and L-64 Canals. The existing Nubbin Slough and Taylor Creek STAs were included in the analysis because those elements place demands on water from the contributory areas in the system and also provide treatment to some water before it reaches Lakeside Ranch.

The four projects were grouped and configured into five primary alternatives, each of which was evaluated using existing and future land-use conditions. The five primary config-

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Table 2: STELLA Preliminary Results Summary, Preliminary Design Phase

	Existing Conditions					Future BMP Conditions				
	PDR-1	PDR-2	PDR-3	PDR-4	PDR-5	PDR-1	PDR-2	PDR-3	PDR-4	PDR-5
TP Load Removal Efficiency, %										
LRSTA	65.2	68.4	63.7	70.9	67.9	69.0	71.9	68.2	74.1	72.1
BRSTA	-	63.4	-	84.2	62.5	-	67.2	-	85.7	67.3
LRRES	-	-	13.1	10.6	-	-	-	11.7	9.8	-
System-Wide	27.4	38.3	28.8	36.8	35.7	21.7	31.7	22.8	29.4	31.4
TP Load Removed, Mton/yr										
LRSTA	22.4	19.6	19.2	16.2	20.5	9.0	8.3	8.0	6.9	10.1
BRSTA	-	13.1	-	11.0	13.9	-	5.7	-	4.5	6.9
LRRES	-	-	4.5	4.2	-	-	-	1.5	-	1.5
TOTAL	22.4	32.7	23.7	31.4	34.4	9.0	14.0	9.5	12.9	17.0
Hydraulic Residence Time, days										
LRSTA	16.9	16.6	21.3	22.8	17.0	16.9	16.7	21.0	23.1	16.9
BRSTA	-	18.9	-	35.0	18.0	-	18.4	-	34.9	17.7
LRRES	-	-	32.9	22.0	-	-	-	34.6	23.1	-

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urations of the LOFT Project preliminary design phase are presented in Table 1.

A summary of the key metrics for each of the five alternatives is provided in Table 2.

From the analysis of alternative configurations and operating rules, the following ranges of the key metrics were observed.

Existing Conditions

TP load removal efficiency varies between 63 to 71 percent at Lakeside Ranch STA, 62 to 85 percent at Brady Ranch STA, and 10 to 14 percent at Lakeside Ranch Reservoir. These values are calculated only on the amount of phosphorus that is pumped into the STAs, in order to measure actual removal effectiveness of TP introduced to the STAs. They do not include external bypasses, which are included in the measures of overall system efficiencies.

TP load removed varies between 16 to 23 metric tons per year (Mton/yr) at Lakeside Ranch STA, 11 to 14 Mton/yr at Brady Ranch STA, and 4.2 to 4.5 Mton/yr at Lakeside Ranch Reservoir. The total TP load removed by these three components ranged from 22 to 35 Mton/yr for existing land use and BMP conditions.

In some cases, the TP load removed in an STA decreased while the removal efficiency increased, or vice versa (such as for LRSTA PDR-1 and PDR-2 when BRSTA was added to the system). This result was due to the change in the influent TP load to the STA. When BRSTA was added to the system, the TP load entering LRSTA decreased, but a greater percentage was removed yielding greater removal efficiency.

Hydraulic residence time varies between 16 to 23 days at Lakeside Ranch STA, 18 to 35 days at Brady Ranch STA, and 22 to 33 days at Lakeside Ranch Reservoir.

Future BMP Conditions

TP load removal efficiency varies between 68 to 75 percent at Lakeside Ranch STA, 67 to 86 percent at Brady Ranch STA, and 9 to 12 percent at Lakeside Ranch Reservoir. These values are calculated only on the amount of phosphorus that is pumped into the STAs, in order to measure actual removal effectiveness of TP introduced to the STAs. They do not include external bypasses, which are included in the measures of overall system efficiencies.

TP load removed varies between 7 to 10 Mton/yr at the Lakeside Ranch STA and 4.5 to 7 Mton/yr at the Brady Ranch STA. The TP load removed at the Lakeside Ranch Reservoir is 1.5 Mton/yr in both scenarios for which it was included. The total TP load removed by these three components ranged from 9 to 17 Mton/yr for future BMP conditions.

In some cases, the TP load removed in an STA decreased while the removal efficiency increased, or vice versa (such as for the Lakeside Ranch STA PDR-6 and PDR-7 when the Brady Ranch STA was added to the system). This result was due to the change in the inflow TP load to the STA. When the Brady Ranch STA was added to the system, the TP load entering the Lakeside Ranch STA decreased but a greater percentage was removed, yielding greater removal efficiency.

Hydraulic residence time varies between 16 to 23 days at Lakeside Ranch the STA, 17 to 35 days at the Brady Ranch STA, and 23 to 35 days at the Lakeside Ranch Reservoir.

Based on the system analysis of the LOFT Project preliminary design using the STELLA model, the following conclusions and recommendations were made:

1. ***Greatest Removal Efficiency***—Overall removal efficiency is greatest when both the Lakeside Ranch STA and Brady Ranch STA operate and Lakeside Ranch Reservoir and S-133 re-routing are excluded (PDR-2 in Table 2); however, the period of hydration in the Lakeside Ranch STA is also least for this scenario. The hydration of the Lakeside Ranch STA could be improved by re-circulating water from the L-47 Canal and Lake Okeechobee, which would also provide additional opportunity for phosphorus removal while hydrating the wetlands. Overall seepage and evaporative losses are less than 5 to 15 percent of the total flow return, and the amount of flow is relatively small compared to the volume of Lake Okeechobee, even during drought conditions.
2. ***Lakeside Ranch Reservoir***—The Lakeside Ranch Reservoir would generally improve drought condition hydration, but would not eliminate frequent dry-out potential. Its inclusion in the system would reduce overall system removal efficiency compared to using the area for the STA. Because the Lakeside Ranch Reservoir would have a higher cost per pound of TP removal and would have a negligible impact on TP removal, its only substantial benefit would be its ability to improve STA hydration; however, it would likely be more cost-effective and simpler to rely on water from the L-47 Canal and Lake Okeechobee to rehydrate the STAs during dry periods, since it could be introduced through existing locks and the planned recirculation loop (L-47 to C-59 to L-63).
3. ***S-133 Re-routing***—Inclusion of the S-133 basin re-routing to the L-63 Canal would yield better hydration in both the Lakeside Ranch and Brady Ranch STAs, since more water would be available by the increased tributary area to the L-63 Canal. For the Brady Ranch STA, the depth was 0.2 ft or less (indicating very dry conditions) 50 percent as often when the S-133 re-routing was included (PDR-2) than when it was not (PDR-5). For the Lakeside Ranch STA, the relative effect is less pronounced, with depths of 0.2 ft or less occurring about 30 percent less often with S-133 re-routing than without when the Brady Ranch STA was also present. Per Table 2, the impact of the S-133 re-routing on TP removal would be approximately 2 Mton/year of additional removal with both the Lakeside Ranch STA and the Brady Ranch STA. This may be a relatively low-cost alternative to improve hydration; however, it does not eliminate the potential for frequent dry-out conditions. The S-133 station is not recommended since the L-47 return flow pump station is already needed for flow return for flood control purposes and has fewer constraints and costs for implementation (the S-133 location has a proposed boat ramp and parking lot).
4. ***Supplemental Hydration Flows from Lake Okeechobee***—This analysis considered three potential means of improving STA hydration during dry periods:
   a. Recirculating seepage and local runoff into the L-47 Canal
   b. Including a storage reservoir on the Lakeside Ranch property
   c. Re-routing S-133 water from the LD-4 Canal

   None of these alternatives significantly reduces the potential for frequent dry-out conditions, though all improve the hydration of the STAs on an average basis. The simplest, most reliable, and most cost-effective means of preventing STA dry-out would be to rely on water from the L-47 Canal and Lake Okeechobee to rehydrate the STAs during dry periods, since it could be introduced through the existing G-36 lock and the planned recirculation loop (L-47 to C-59 to L-63). The output of this evaluation suggested that the need for a more reliable supplemental source (such as the L-47 Canal or Lake Okeechobee) is necessary, especially if both the Lakeside Ranch STA and the Brady Ranch STA will be built and operated.
5. ***Implementation***—Based on these analyses, the implementation of the Lakeside Ranch

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Figure 6: Lakeside Ranch STA Design

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STA and the Brady Ranch STA is recommended, along with recirculation of flow from the L-47 Canal and Lake Okeechobee to provide hydration during dry conditions and additional treatment of flows from the S-135 basin and from Lake Okeechobee.

One finding from the basis of design and preliminary design analyses was that the amount of water available from Taylor Creek and Nubbin Slough was not sufficient to keep the proposed Lakeside Ranch STA hydrated at all times, even in the absence of the potential Brady Ranch STA. In the event that an STA becomes dehydrated (dries out), oxidation of its sediments can result in the release of phosphorus after the STA is rehydrated; therefore, it is critical that an STA be kept hydrated in order to effectively provide long-term capture of phosphorus from the watershed runoff.

Subsequent to the preliminary design phase, additional modeling in STELLA was performed to support the final design of the Lakeside Ranch STA. For this evaluation, the model was refined to include flow return from Lake Okeechobee for hydration of the Lakeside Ranch STA and the Brady Ranch STA.

In this scenario, Lake Okeechobee water would be routed through the G-36 Lock into the L-47 Canal when treatment capacity is available in the Lakeside Ranch STA and the Brady Ranch STA. The lake water would be pumped by the S-191 pump station from the L-47 Canal to the C-59 Canal and onto the L-63S and L-64 Canals.

The baseline configuration for this evaluation included the existing Taylor Creek and Nubbin Slough STAs and excluded re-routed flows from the S-133 and S-154 basins. Based on the findings of the basis of design and preliminary design phases, the proposed reservoir at Taylor Creek was also excluded from this analysis.

As shown on Figure 6, the current design of the Lakeside Ranch STA was divided into two phases (LRSTA North and LRSTA South), whereas the previous modeling efforts were based on a single phase design. The areas of LRSTA North and LRSTA South are 933 and 838 acres, respectively; the area of the potential Brady Ranch STA is 1,600 acres. The area of LRSTA South does not include the 175-acre southeast forested area, which may provide additional treatment when flooded.

The existing model was used to evaluate the phosphorous removal and STA hydration benefits of flow return from Lake Okeechobee when treatment capacity was available at Lakeside Ranch and Brady Ranch. The conclusions from this evaluation are:

- Flow return from Lake Okeechobee improved both the system TP removal efficiency and the total mass of TP removed by the system. With LRSTA North, LRSTA South, and the Brady Ranch STA implemented under existing land-use conditions, flow return from Lake Okeechobee increased the TP load removed by 8 Mtons/yr, which represents an increase in system-wide removal efficiency of 3 percent. This benefit is significant when considering the relatively minor cost of implementing flow return from Lake Okeechobee (power costs for the proposed S-191 station).
- Although future decreases in TP concentrations in Lake Okeechobee would diminish system performance when compared to current TP concentrations, the flow return from Lake Okeechobee would still have a positive benefit in terms of mass TP removed and the hydration of the Lakeside Ranch STA and the Brady Ranch STA.

The model simulations of six scenarios (three configurations of the Lakeside Ranch STA and the Brady Ranch STA and two land-use conditions) showed flow return from Lake Okeechobee would increase the overall system TP removal efficiency because of improved hydration of the Lakeside Ranch STA and the Brady Ranch STA. These benefits are significant when considering the relatively minor cost of implementing flow return from Lake Okeechobee. It was recommended to the South Florida Water Management District that this option be pursued to increase TP removal while maintaining STA hydration of the proposed LOFT projects.