Chapter 9: Kissimmee River Restoration and Basin Initiatives

Joseph W. Koebel, Stephen G. Bousquin, David H. Anderson, Michael D. Cheek,
Camille Carroll, Hongjun Chen, Charles Hanlon, Zach Welch, Brent C. Anderson,
Lawrence Spencer, Tyler Beck[1], and Arnold Brunell[1]

Contributor: Tim Coughlin[1] and Seán Sculley

SUMMARY

The Kissimmee Watershed experienced above average rainfall in Water Year 2018 (WY2018; May 1, 2017–April 30, 2018). Rainfall was 10 inches above average across the watershed, with 51.69 inches falling over the Upper Kissimmee Basin and 55.92 inches over the Lower Kissimmee Basin. With Kissimmee River Restoration Project (KRRP) land acquisition and construction not expected to be completed until late 2020, the Interim Period between the start of construction and implementation of the Headwaters Revitalization regulation schedule will expand to more than 19 years. Operation of the S-65 water control structure faced challenges from heavy rainfall in early June 2017 and Hurricane Irma in September 2017; it was operated to meet often competing objectives in WY2018. In S-65 wet season operations, improving Kissimmee River floodplain inundation was at odds with minimizing flows to Lake Okeechobee and providing desired stage ascension rates favorable for apple snails and other wildlife in the Headwaters Lakes (Lakes Kissimmee, Cypress, and Hatchineha). A spreadsheet model simulation showed that had the recommended HRS-14-50 discharge plan been fully implemented, the duration of Kissimmee River floodplain inundation in WY2018 would have increased by 56%, from 79 to 123 days. Despite below average rainfall in the dry season, fish and wildlife stage recession rates for Lake East Tohopekaliga, Lake Tohopekaliga, and the Headwaters Lakes were slightly below the ranges of preferred recession rates. Discharge from S-65A was less than 1,000 cubic feet per second (cfs) for most of the dry season, which facilitated United States Army Corps of Engineers (USACE) backfilling for the KRRP but did not provide sufficient volume to inundate the Kissimmee River floodplain for even short periods.

This chapter reports results of numerous monitoring studies being conducted in the Lower Kissimmee Basin by the Kissimmee River Restoration Evaluation Program (KRREP) and in the Upper Kissimmee Basin by both the South Florida Water Management District (SFWMD or District) and partner agencies. Results are reported in any given year as new data and analyses become available. Brief abstracts of study findings are presented here; for full results and other details such as study methods, refer to the corresponding subsections later in the chapter.

---

[1] Florida Fish and Wildlife Conservation Commission, Northeast Region, Ocala, Florida.

LOWER KISSIMMEE BASIN (KRREP)

- **KRREP Hydrology**. Targets for KRREP Expectation 3, Hydroperiod Requirements for Broadleaf Marsh (BLM), the dominant and most characteristic wetland plant community of the pre-channelization floodplain, and Expectation 4, recession rates, were evaluated for WY2018. Only one floodplain inundation event occurred in WY2018 that met the depth criterion of at least 1 ft, and it lasted for only 63 days, far shorter than the 210-day duration criterion. The recession rates associated with this event and a shallower inundation event exceeded the 1 ft per 30 days maximum recession rate criterion. Consequently, the expectation targets were not met in WY2018 for either expectation. The targets for Expectations 3 and 4 have not been met in any year of the Interim Period (2001–2018). While it may not be possible to fully meet the targets of these two expectations prior to implementation of the Headwaters Revitalization Schedule (HRS), performance can be improved now by implementation of discharge plans that use 1,400 cfs as a minimum discharge when Headwaters Lakes stage is above a specified threshold stage. Closely following recommended discharge plans in future years is suggested to improve hydrologic performance for the KRRP.
- **KRREP Dissolved Oxygen.** Concentrations of daytime dissolved oxygen (DO) in the river channel of the Phase I restoration area continued to be higher in WY2018 than pre-restoration levels. Of the four metrics used to evaluate DO response, two were met in WY2018. Mean daytime DO concentrations exceeded the dry season (November–May) target range but fell just short of the wet season (June–October) target range in WY2018. The third metric, frequency of DO concentration > 1 milligram per liter (mg/L) within 1 meter (m) of the channel bottom, exceeded its 50% target. The fourth metric, frequency of concentrations > 2.0 mg/L, fell 12% short of its 90% target, reflecting periods of hypoxic/anoxic conditions in the river channel.
- **KRREP Floodplain Vegetation.** A vegetation map based on 2015 aerial imagery of the Phase I restoration construction area was completed and compared to previous maps dating back to 1952. The target for Expectation 12 for Wetland Vegetation was met soon after Phase I was completed and has continued to be met. However, the expectation for BLM coverage (Expectation 13) has never been met in the Interim Period due to short hydroperiods and likely also to invasions of exotic species. Wet Prairie cover (Expectation 14) has remained steady in recent maps but is much higher than pre-regulation (1952) coverage, reflecting that much of the current cover of Wet Prairie occurs in historically BLM areas, where hydroperiods in the Interim Period have been too short for BLM. Much of the floodplain is dominated by exotic grasses, primarily para grass (*Urocloa mutica*) and West Indian marsh grass (*Hymenachne amplexicaulis*). The District has been testing management techniques to control these invasions, and the combination of these techniques with upcoming changes in flooding regimes under the HRS hopefully will begin to limit invasive species.
- **KRREP Largemouth Bass Response to the Summer 2017 Kissimmee River Anoxic/Hypoxic Events.** Fish in the Kissimmee River were exposed to potentially lethal, low oxygen conditions (DO < 1.0 mg/L) for 12 consecutive days in June-July 2017 and five consecutive days in September 2017. In addition, stressful conditions (DO > 1.0 mg/L but < 2.0 mg/L) were present 41 days in summer 2017. After these events, bass declined drastically and had not recovered by spring 2018. Bluegill (*Lepomis macrochirus*) also were impacted by the hypoxic events but appear to have recovered quickly. Few bass were collected in the river in summer 2017 and less than 20 were collected in winter 2017 and spring 2018, suggesting the population may take years to recover. The combined stress of annual lethal and stressful oxygen events and a frequent lack of access to the floodplain during peak spawning season appear to be making it difficult for largemouth bass to thrive in the Kissimmee River.

- **KRREP Wading Bird Abundance.** Dry season monthly wading bird surveys in restored portions of the river during the 2017-2018 dry season indicated that the three-year (2016–2018) running average was not significantly different from the restoration expectation of 30.6 birds per square kilometer (birds/km^2). However, the long-term mean annual three-year running mean (2002–2018) was significantly higher than the restoration expectation of 30.6 birds/km^2, suggesting a pronounced positive response.
- **KRREP Waterfowl Abundance.** Dry season waterfowl abundance was the highest recorded since Phase I construction was completed in 2001. The long-term (2002–2018) mean annual three-year running average of waterfowl abundance was significantly greater than the restoration expectation of 3.9 birds/km^2. The restoration target for waterfowl species richness has not yet been reached.
- **KRREP Wading Bird Nesting.** Eight colonies were active during the 2018 season within the KRRP area and Lakes Istokpoga and Kissimmee. The peak number of aquatic wading bird nests (excluding cattle egrets [*Bubulcus ibis*]) documented throughout the basin was 3,542 nests for any sampling event.

UPPER KISSIMMEE BASIN

- **Vegetation Monitoring.** The District completed the third year of data collection in long-term vegetation monitoring plots in East Lake Tohopekaliga, Lake Tohopekaliga, and Lake Kissimmee. The plots are intended to establish baseline conditions for comparison with data collected after completion of the KRRP, which will coincide with HRS implementation.
- **Fisheries.** The Florida Fish and Wildlife Conservation Commission (FWC) electrofishing data from spring 2017 for Lakes Tohopekaliga, Cypress, Kissimmee, Hatchineha, and Marian showed high variability between lakes and when compared with previous years' data. Lake Kissimmee had low numbers of subadults (< 25 centimeters [cm]) but high numbers of larger adult bass (> 25 cm). Results were opposite at Lake Tohopekaliga, which had the highest number of adult fish sampled but a very low number of subadults compared with other lakes, except Lake Marian. Lakes Cypress and Hatchineha had average catches and distributions of young and adult fish.
- **Snail Kites.** During the 2017 breeding season, all regions saw very low snail kite (*Rostrhamus sociabilis plumbeus*) nesting activity likely due to very dry conditions early in the nesting season. Like previous years, the Kissimmee Chain of Lakes (KCOL) supported 24% of the statewide nesting activity; however, this represented the lowest number of active nests (53) in the region since 2006 and the third lowest number of successful nests (18). Consistent with shifting patterns seen in snail kite use of habitats across South Florida, the KCOL has had fewer total nests, successful nests, and fledglings produced in the past three years than other regions in the state. This trend is primarily due to increases in total nests and successful nests in other areas of the state, and decreases on East Lake Tohopekaliga and Lake Tohopekaliga, although these trends were less pronounced this year due to overall poor nesting.
- **Alligators.** The FWC monitors American alligator populations using spotlight surveys at night, which showed very high populations on Lakes Tohopekaliga, Kissimmee, and Hatchineha for the 2017 sampling period. Populations for all three lakes were the highest or second highest recorded since surveys began and a rebound from lower numbers in 2016. East Lake Tohopekaliga and Lake Cypress continue to show stable populations with modest increases or decreases in this year's population compared to initial surveys in the early-2000s.

INTRODUCTION

The District continues to coordinate with USACE on the KRRP. In addition, SFWMD is integrating KRRP with management activities throughout the Kissimmee Basin and Northern Everglades region. The primary goals of these efforts are to (1) restore ecological integrity to the Kissimmee River and its floodplain, (2) collect ecological data to evaluate river restoration and support water management decision making, (3) enhance and sustain natural resource values in the KCOL, and (4) retain the flood reduction benefits of the Central and Southern Florida Flood Control Project (C&SF Project) in the Kissimmee Basin. In addition to projects under the KRRP, SFWMD also manages the KCOL and Kissimmee Upper Basin Monitoring and Assessment Project. See Koebel et al. 2018 for historical information about the KRRP and development of the KRREP.

This year's update on the KRREP evaluations includes analyses of newly available data from studies of hydrology, DO, fish population, wading birds, waterfowl, and floodplain vegetation. This subset of restoration evaluation studies assesses the level of response of critical ecosystem components to physical restoration under interim (pre-project completion) hydrologic conditions based on new data that have not been reported in previous *South Florida Environmental Report* (SFER) – *Volume I* chapters. Results from these studies provide information for sound water management decision making as the KRRP progresses and will guide water management after the project is complete.

The Kissimmee Basin includes more than two dozen lakes in the KCOL, their tributary streams and associated marshes, and the Kissimmee River and floodplain (**Figures 9-1** and **9-2**). The basin forms the headwaters of Lake Okeechobee and the Everglades; together, they compose the Kissimmee-Okeechobee-Everglades system. In the 1960s, the C&SF Project extensively modified the Kissimmee Basin's water resources by constructing canals and installing water control structures for flood control. In the LKB, construction of a 56-mile long canal through the Kissimmee River resulted in profound negative ecological consequences caused by elimination of flow in the original river channel, which prevented seasonal floodplain inundation. These and other environmental losses led to legislation authorizing the federal-state KRRP. The District has been working since the early 1990s to coordinate, operate, and evaluate the KRRP through KRREP. See Koebel and Bousquin (2014) for more details regarding environmental losses in the LKB.

The KRREP is integrated with other management activities in the Kissimmee Basin and the Northern Everglades region. The primary goals of these efforts are to (1) restore ecological integrity to the Kissimmee River and its floodplain, (2) collect ecological data to evaluate river restoration and support water management decision making, (3) enhance and sustain natural resource values in the KCOL, and (4) retain the C&SF Project's flood reduction benefits in the Kissimmee Basin. The geographic scopes of projects in the Kissimmee Basin are shown in **Figure 9-3**.

This chapter is an update to Chapter 9 of the 2018 SFER – Volume I (Koebel et al. 2018). It focuses on the status of Kissimmee Basin projects during WY2018. The chapter also summarizes hydrologic conditions and water management during WY2018 and presents newly available data from KRRP evaluations and other monitoring and management activities from certain lakes in the KCOL.

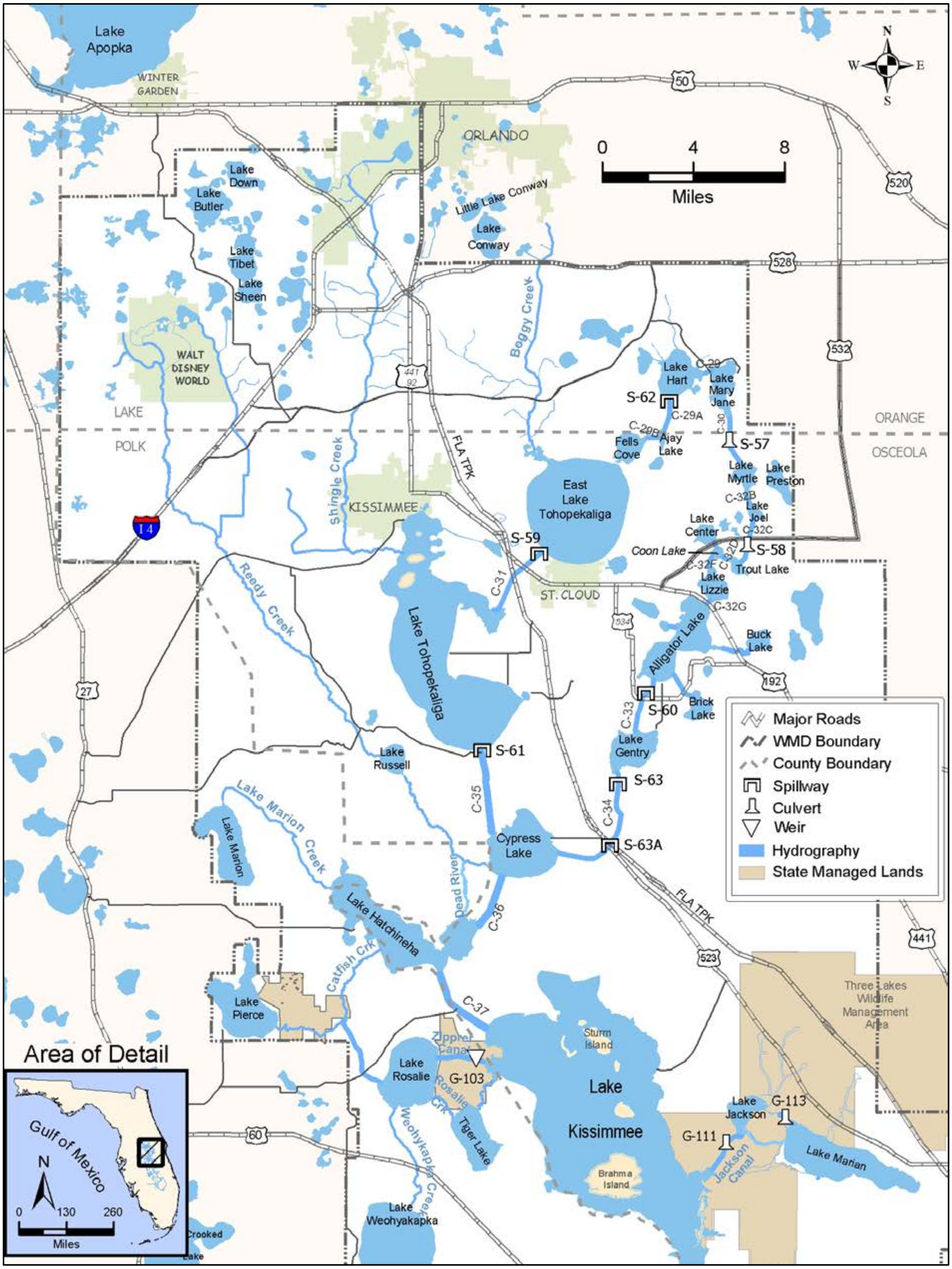


Figure 9-1. Upper Kissimmee Basin. (Note: WMD – South Florida Water Management District.)

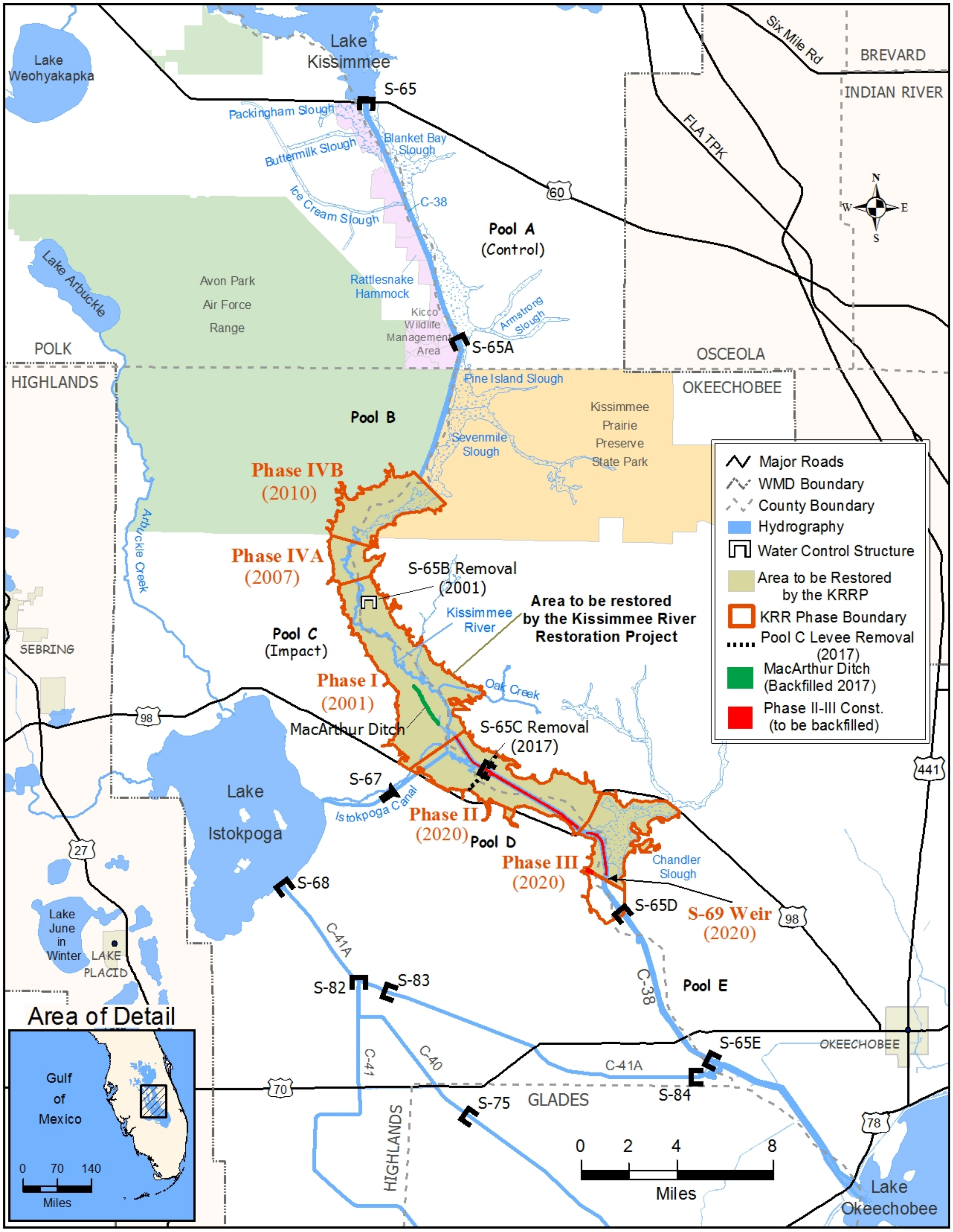


Figure 9-2. Lower Kissimmee Basin with actual and projected completion dates of construction phases. (Note: KRR – Kissimmee River Restoration.)

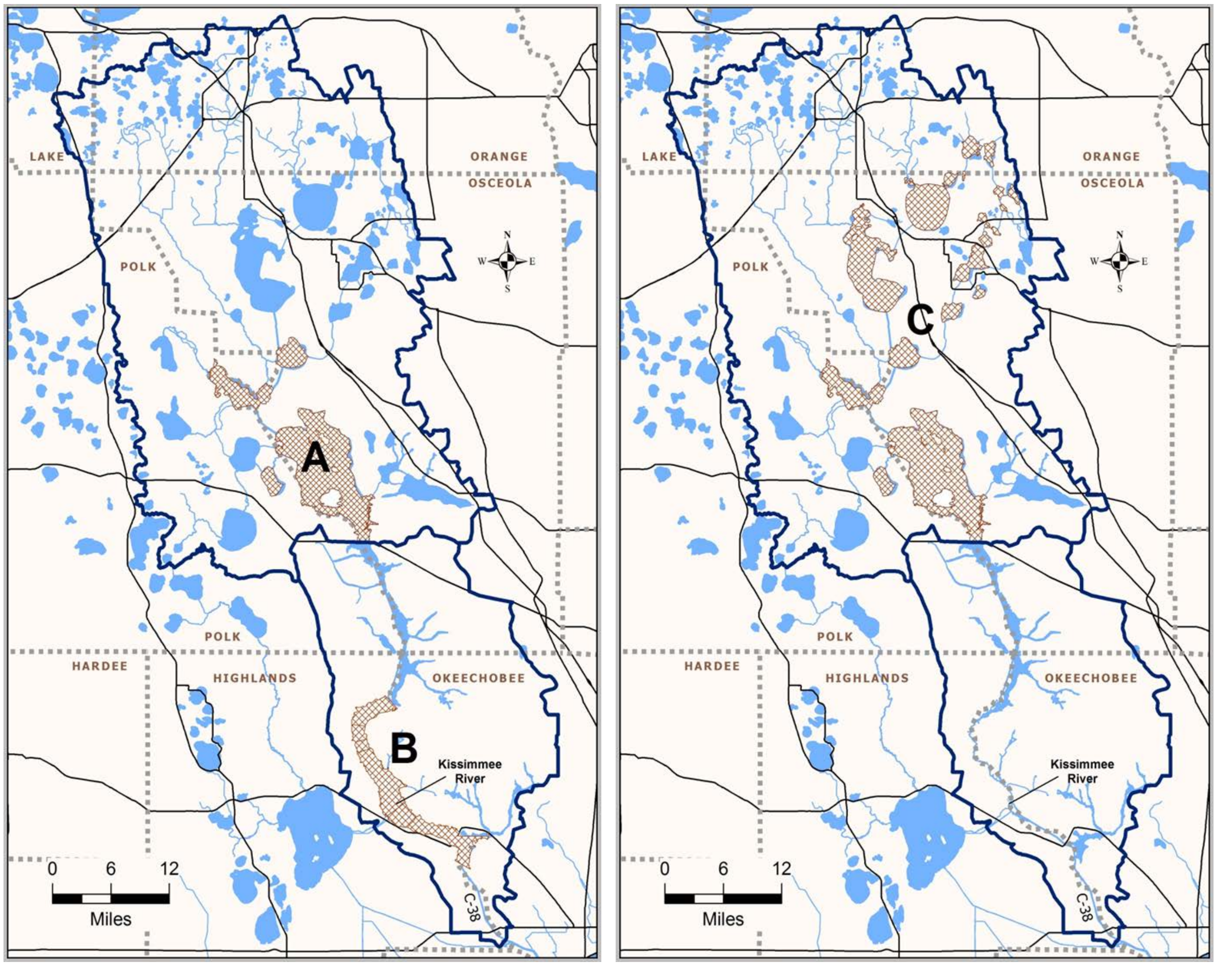


Figure 9-3. Geographic scopes (colored, hatched areas on maps) of major initiatives in the Kissimmee Basin including the (A) Headwaters Lakes components of KRRP, (B) KRRP, and (C) KCOL and Kissimmee Upper Basin Monitoring and Assessment Project.

KISSIMMEE RIVER RESTORATION PROJECT UPDATE

RESTORATION CONSTRUCTION COMPONENTS

Reconstruction of the river floodplain's physical template is being implemented in four construction phases (**Table 9-1**), currently projected for completion in 2020. Phases II and III (Reaches 2 and 3) are the last major phases of construction. Phase III began in 2015 and was completed in 2016. The Phase II contract was awarded in January 2016 and is scheduled for completion in 2019. Construction of the S-69 weir, which will serve as the terminus of the backfilled sections of canal, is projected for completion in 2020. See Koebel et al. 2018 for more details regarding restoration construction.

The KRRP will culminate with modification of the Kissimmee Basin water control structure operations, including implementation of the HRS to operate the S-65 water control structure. The HRS will allow lake water levels to rise 1.5 ft higher than the current S-65 schedule and will increase the water storage capacity of Lakes Kissimmee, Hatchineha, Cypress, and Tiger by approximately 100,000 acre-feet (ac-ft). This will allow delivery of flows that closely approximate the historical flows needed for restoration of the Kissimmee River and its floodplain wetlands. Ninety-nine percent of the 36,612 acres (ac) of land in the UKB that will be affected by the higher water levels have been acquired, and all projects needed to increase the conveyance capacity of UKB canals and structures are in place to accommodate the larger storage volume. The few remaining lands are expected to be acquired in 2019.

Table 9-1. Sequence of backfilling construction phases of KRRP with selected benefits.

Construction Sequence	Name of Construction Phase	Timeline	Backfilled Canal (miles)	River Channel Recarved (miles)	River Channel to Receive Reestablished Flow (miles)	Total Area (ac)	Wetland Gained (ac)	Location and Other Notes
1	Phase I Project Area	1999–2001 (complete)	7.5	1	14	9,506	5,792	Most of Pool C, small section of lower Pool B
2	Phase IVA Project Area	2006–2007 (complete)	2	1	4	1,352	512	Upstream of Phase I in Pool B to Weir #1
3	Phase IVB Project Area	2008–2010 (complete)	3.5	4	6	4,183	1,406	Upstream of Phase IVA in Pool B (upper limit near location of Weir #3)
4	Phases II and III Project Areas	2015-2020 (projected)	9	4	16	9,921	4,688	Downstream of Phase I (lower Pool C and Pool D south to the CSX Railroad bridge)
Restoration Project Totals			**22**	**10**	**40**	**24,963**	**12,398**	

Because of the time lag between completion of the first phase of construction and implementation of the HRS, USACE authorized an interim regulation schedule in 2001 for S-65 that allows SFWMD to make releases from S-65 when its headwater stage is within a certain range (termed “Zone B”) below the maximum regulated stage. Zone B allows releases from S-65 for environmental purposes when flood control releases (stage above the regulation line or Zone A) are not needed. It is used to maintain flow in the reach of the restored river channel throughout the year and to allow seasonal variability. Environmental releases according to this interim schedule began in July 2001, after Phase I construction was completed and lake levels began to rise following the 2000–2001 drought. Zone B releases have allowed continuous flow to the river since that time except for a 252-day period of drought in 2006–2007. The use of Zone B releases has been beneficial to the hydrology of completed sections of the KRRP, but it does not provide the full benefits the HRS is expected to provide when implemented.

CONSTRUCTION STATUS

The Reach 2 backfilling contract was awarded by USACE in 2016. Backfill of the C-38 canal in the Reach 2 area began in January 2017 (**Figure 9-4**) and will continue into 2019. The $26.13 million Reach 2 contract is filling an additional 7 miles of the C-38 canal and has removed water control structure S-65C, routing water to the native channel and floodplain of the Kissimmee River, which reestablishes hydrologic continuity between the river and floodplain in former Pools C and D for the first time since the C-38 canal was completed in 1971. Reach 2 backfill was nearly complete in early September 2017 when Hurricane Irma produced extremely high discharge and flooding throughout the Reach 2 construction area, which resulted in severe erosion of the recent backfill. The high water and discharge associated with Hurricane Irma also caused erosion in the Reach 3 restoration area, which was previously completed in 2016. Both areas are being surveyed for erosion and evaluated for repair. **Table 9-2** provides brief descriptions of remaining construction activities. A complete list can be found in Koebel et al. (2017).

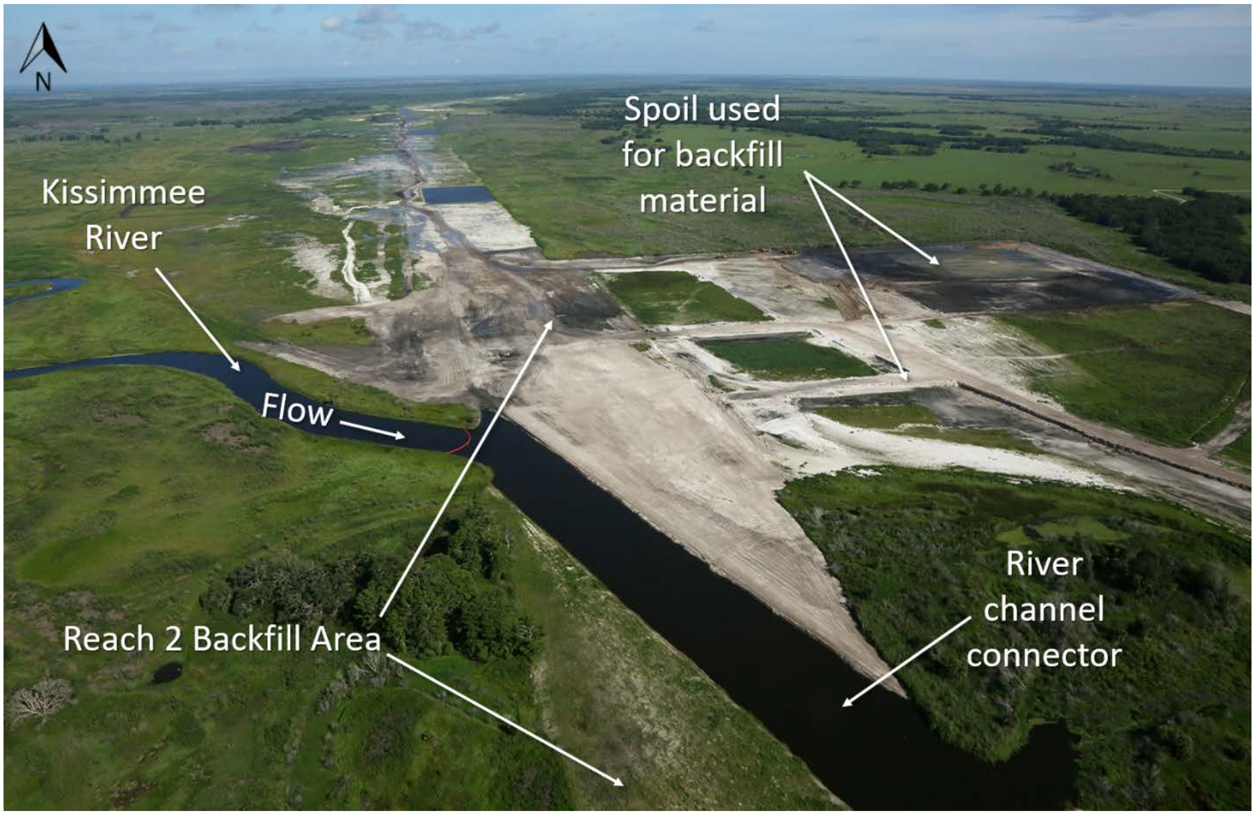


Figure 9-4. KRRP Reach 2 backfilling progress.

Table 9-2. Remaining KRRP construction.
See Koebel et al. (2017) for a complete chronology of construction events.

Contract Number	Project Name and Description	Status	Construction		
			Projected or Actual Start Date	Projected or Actual End Date	Cost
10	Reach 2 Backfilling – New channels will be dredged, 6.5 miles of the C-38 canal will be backfilled, and the S-65C structure will be removed.	Under construction	January 2017	January 2019	$26.1 million
12A	S-69 Weir – The S-69 weir will serve as the terminus of the C-38 canal backfill, maximizing the area of wetlands to be rehydrated in the Kissimmee River floodplain. The weir will dissipate the energy of flood flows as they transition from the Kissimmee River floodplain to the remnant C-38 channel.	Awarded 2017	November 2018	October 2020	$15–$25 million

Note: Dates and costs do not include repair costs for erosion damages in Reach 2 and Reach 3 backfilling caused by Hurricane Irma.

KISSIMMEE BASIN HYDROLOGIC CONDITIONS AND WATER MANAGEMENT IN PLANNING WINDOW 2017-2018

This section describes hydrologic conditions in the UKB and LKB and their relationship to water management activities in Planning Window 2017-2018, which includes the 2017 (June-October) wet season and the 2017-2018 (November 2017-May 2018) dry season. The planning window aligns with operational planning for the wet and dry seasons; unlike the water year, which brackets the wet season with one month of the preceding dry season and the first seven months of the next dry season. The narrative focuses on the timing and quantity of rainfall in the Kissimmee Basin and the water management and rainfall-driven temporal patterns of discharge and stage that resulted.

In the LKB, SFWMD uses water control structures S-65, S-65A, S-65C (through February 2017 when S-65CX was removed and the S-65C gates were locked open), and S-65D (which became the project's downstream control structure starting in February 2017) to manage flow to and water levels in the Kissimmee River and its floodplain, where USACE and SFWMD have completed four of five physical reconstruction phases of KRRP since 2001. Removal of S-65CX, the associated tieback levee, and the S-65C structure itself are part of the KRRP Reach 2 construction contract (see the *Construction Status* subsection earlier in the chapter). This work is designed to allow recovery of the river floodplain ecosystem with appropriate water management per the authorized project objectives.

In the UKB, SFWMD manages water levels in the KCOL, which is divided into seven groups of one or more lakes interconnected by canals. Each group of lakes is regulated by a single water control structure (**Figure 9-1**). Surface water from the northern UKB flows to the Headwaters Lakes before being discharged through water control structures S-65 and S-65A to the C-38 canal, which flows to reconstructed sections of KRRP (**Figure 9-2**). Because the Kissimmee River and its floodplain slope to the south, it is not possible to store large volumes of water in reconstructed sections of the KRRP; most of the water discharged from S-65 quickly leaves the Kissimmee Basin at S-65E, where it continues to Lake Okeechobee. Discharge from S-65 through S-65A therefore is the primary determinant of flow in the river channel (as opposed to direct rainfall and watershed runoff), and the only way to generate the overbank flow needed to provide sufficient inundation of the floodplain for restoration is to provide prolonged, uninterrupted periods of discharge more than 1,400 cfs (current estimate) through these structures.

Completion of restoration construction in 2020 and implementation of the HRS are expected to provide additional upstream water storage for restoration of the Kissimmee River and its floodplain. However, appropriate water management during the Interim Period could realize substantial ecological benefits in the northern Phase I and Phase IV floodplain (**Figure 9-2**), where restoration construction has been completed. These benefits include improvements in reestablishment of long-hydroperiod floodplain marshes and recovery of the fish and wildlife that depend on access to them and other wetlands. While the floodplain inundation targets are not anticipated to be fully met during the Interim Period, performance for these targets can be improved, as discussed in the *Hydrology* subsection later in this chapter.

Via S-65A, S-65 provides the dominant source of flow to reconstructed sections of the Kissimmee River and floodplain, but as water is released, stages in the Headwaters Lakes decline unless rainfall and runoff into the lakes offsets the releases. For this reason, stage targets for the Headwaters Lakes often conflict with the goals of the KRRP, particularly when high lake stages are targeted without consideration of discharges needed to meet KRRP hydrologic objectives. Releases from other water bodies upstream of the Headwaters Lakes, especially Lake Tohopekaliga and East Lake Tohopekaliga (e.g., for flood control in those lakes or to meet stage targets), also impact stage in the Headwaters Lakes. Therefore, in addition to indirectly affecting operations for the KRRP, operations for upstream lakes may also inhibit meeting stage targets in the Headwaters Lakes.

The stage regulation schedules authorized by USACE for each water control structure in the KCOL have a strong influence on temporal hydrologic patterns in the Kissimmee Basin (**Figure 9-5**). Each water control structure controls stage in one or more lakes within a defined lake group (**Figure 9-1**), and each lake group has a regulation schedule associated with its water control structure (e.g., **Figures 9-10** and **9-11** later in this chapter). All the KCOL regulation schedules have a similar shape, declining in the spring to their lowest elevations ("low pool") on May 31 to create storage for wet season rainfall, rising to a plateau ("summer pool") on June 1 to accommodate early summer rainfall, and rising to their highest elevations ("high pool" or "winter pool") on November 1 (**Figure 9-5**) to provide additional storage for rainfall, which typically peaks in late wet season. Starting in February for the Headwaters Lakes, December for Lakes Myrtle-Preston-Joel, and mid-March for the other KCOL lakes, the schedules then recede again to their low pool stages on May 31 to provide capacity for the upcoming wet season. The regulation schedule lines specify seasonally varying maximum water elevations that, when exceeded (Zone A in **Figure 9-5**), trigger mandatory flood control releases to bring lake stage back to or below the regulation lines. When lake stage is at or below the regulation line (Zone B in **Figure 9-5**), water can be discharged for environmental purposes. For example, S-65 (controlling the Headwaters Lakes) can be operated below its regulation line to release water to KRRP to achieve restoration goals, or to allow lake stage recession or ascension objectives in the Headwaters Lakes. For this discussion, discharge operations that release water to meet environmental goals when stage is below the regulation line are called discretionary releases (as opposed to mandatory releases for flood control when a regulation line is exceeded). Thus, stage regulation schedules do not represent required or desirable lake stages; they specify only the maximum stage at which the lake or lake group may be operated.

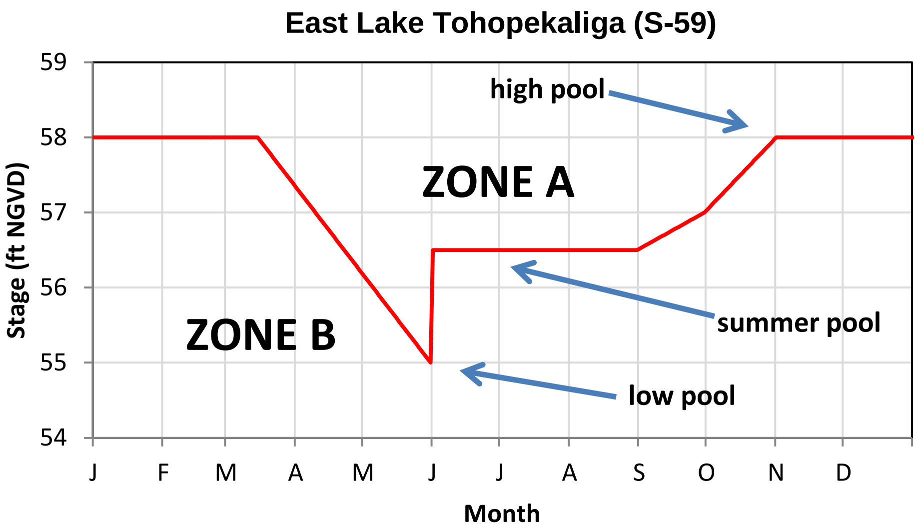


Figure 9-5. Example regulation schedule (East Lake Tohopekaliga) showing the regulation line (red) that separates Zone A (above the line) from Zone B (below the line). When lake stage is in Zone A, releases are mandatory for flood control; when stage is in Zone B, releases are discretionary for environmental purposes. All lakes in the KCOL have a similar schedule with a Zone A and Zone B.

The Kissimmee Basin is an ecosystem in which the progress and success of a federally authorized $800 million ecosystem restoration project with mandated hydrologic and ecological goals (KRRP), nesting habitat for an endangered species (the Everglade snail kite in the KCOL and Kissimmee River) and demands from downstream ecosystems (including Lake Okeechobee and the St. Lucie and Caloosahatchee estuaries) are factors in water management decisions. In addition to the KRRP, three of the UKB lake groups—Headwaters Lakes, Lake Tohopekaliga, and East Lake Tohopekaliga—are a focus of discretionary water management in the Kissimmee Basin, which typically involves manipulation of discharge from these lakes. In WY2018, an additional factor was in play—ongoing KRRP Reach 2 backfilling operations could benefit from river flow rates that were less than required to inundate the floodplain. In addition to these divergent demands, the SFWMD must maintain the pre-project level of flood control and work within the physical limitations of the system (e.g., the operational constraints and conveyance capacities of structures) and environmental conditions (e.g., rainfall) to achieve the best possible outcomes.

Delivering flows from the Headwaters Lakes to the restored portion of the Kissimmee River for improved floodplain inundation depth and duration sometimes conflict with other objectives. For example, in WY2018, Headwaters Lakes discharge was reduced and stage was kept as high as the regulation stage to reduce the volume of flow to Lake Okeechobee. As a result, floodplain inundation duration in WY2018 fell further short of its target, with minimal benefit to Lake Okeechobee stage (the volume of 1 foot of Headwaters Lakes storage equates to 1.5 inches of depth on Lake Okeechobee). Another example occurred during the WY2018 dry season when alternative recession rates for the Headwaters Lakes were used to enhance Everglade snail kite nesting opportunities on the lakes. As a result, floodplain-inundating S-65/S-65A discharges of 1,400 cfs or more did not occur during the dry season, except for a few days in early November 2017.

Wet and dry season planning typically involves modeling to determine how proposed operations are likely to affect water levels in the Headwaters Lakes, discharge to the Kissimmee River, and the volumes of water originating in the UKB that are released to Lake Okeechobee. Analysis of model output uses analog years based on climatic outlooks and past rainfall. Most importantly, these analyses provide a better understanding of the tradeoffs among operational plans and the probable frequency of occurrence of desired conditions over long periods of time, rather than targeting goals to be met in years in which conditions may not be suitable to achieve them.

In this section, hydrologic conditions for WY2018 were quantified with data collected by SFWMD's hydrologic monitoring program at water control structures throughout the Kissimmee Basin (**Figures 9-1** and **9-2**) and stage monitoring locations distributed in the Kissimmee River channel and floodplain (**Figure 9-6**). The section follows the conventions of SFWMD and USACE water managers by reporting hydrologic variables in English units—inches for rainfall, ft NGVD29 for stage and depth, and cfs for discharge.

Hydrology in the KRRP Phase I floodplain is complex; its dynamics were characterized for WY2018 using two metrics—mean depth at floodplain BLM sites (referred to as BLM depth) and mean depth on the Kissimmee River floodplain (referred to as mean depth). Each BLM site has a stage recorder; mean daily stage (water surface elevation) was converted to water depth by subtracting the average ground elevation within a 100-ft radius centered on the stage recorder in a surveyed digital elevation model. BLM depth was calculated as the average depth at five stations in the northern floodplain at which BLM vegetation occurred prior to regulation (pre-1962, before construction of the C-38 canal) and where BLM is expected to reestablish after restoration construction is completed and historic hydrology is restored (see *Hydrology* subsection of the *Kissimmee River Restoration Evaluation Program* section of this chapter). The five stations were selected because they are in the northern floodplain of the Phase I area and thus are outside the direct influence of the headwater stage of the former (through February 2017) downstream water control structure (S-65C), and for concurrence with Expectation 3, also evaluated in the *Kissimmee River Restoration Evaluation Program* section of this chapter.

BLM, which has very long hydroperiod requirements (see the *Expectation 3* subsection of the *Kissimmee River Restoration Evaluation Program* section) was the predominant wetland plant community on the floodplain prior to channelization and, with appropriate water management, is expected to cover more than 50% of the Kissimmee River floodplain after restoration construction is completed and historic hydrology is reestablished. Mean depth is the average depth in the Phase I floodplain, estimated using interpolations of mean daily stage measurements from a network of stage recorders in the Phase I area. The interpolations are used to create a grid of water surface elevations, which are compared to ground elevations from a digital elevation model. Ground elevation is subtracted from the water surface elevation to obtain an estimated depth for each 30-ft × 30-ft grid cell. Mean depth for the Phase I area is the average of depths of individual grid cells on a given date. Thus, mean depth provides an indication of conditions throughout the Phase I area, including the southern floodplain where depth has been influenced by a backwater effect of S-65C (Anderson 2014). BLM depth and mean depth exhibit similar trends, but BLM depth exhibits a greater range of fluctuation.

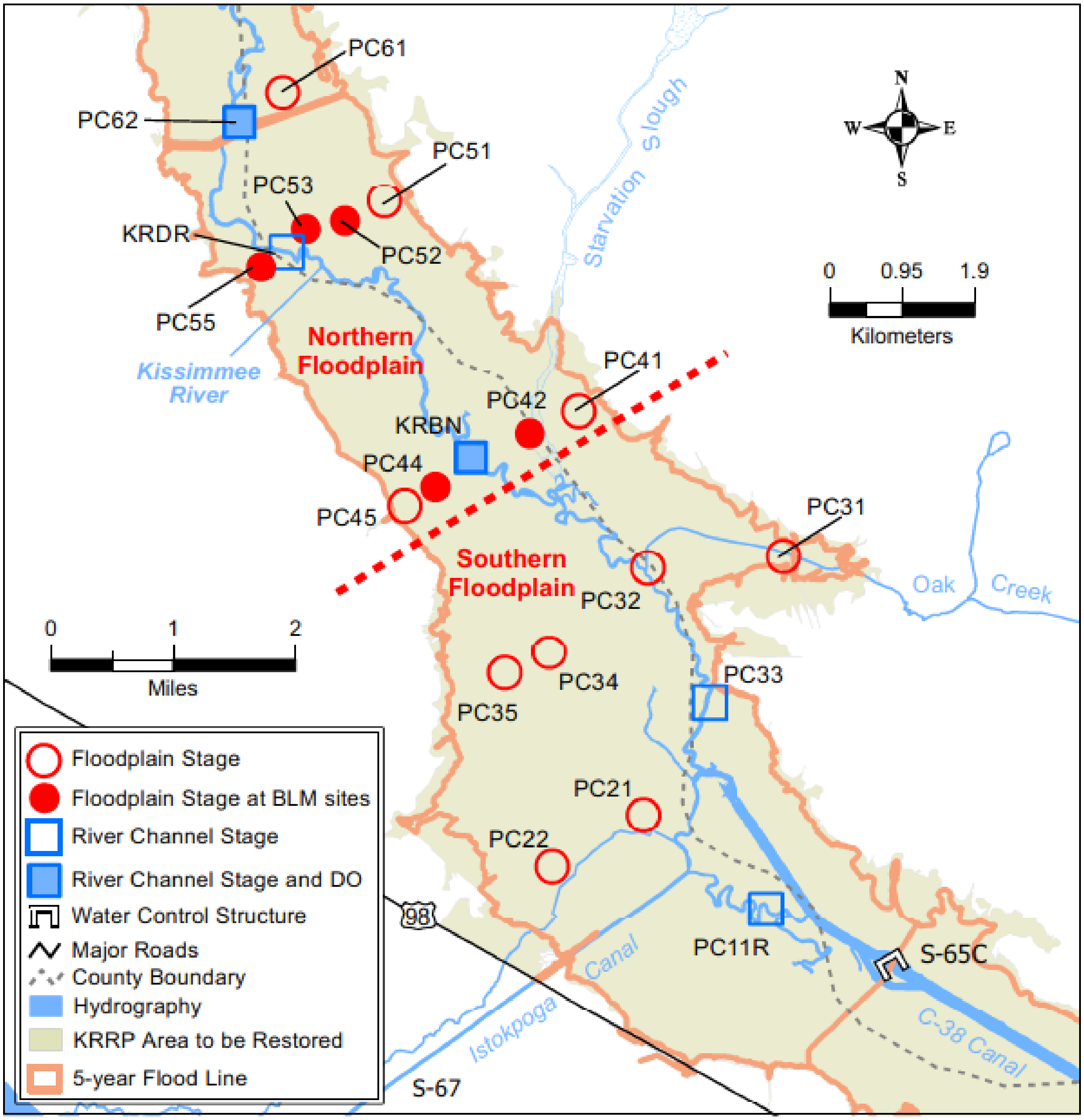


Figure 9-6. Locations of hydrologic monitoring sites in Pool C used to guide operations and evaluate restoration expectations.

RAINFALL

Total rainfall was above average in the UKB and LKB for the 12-month period (**Figure 9-7**). Total rainfall in the UKB was 58.0 inches (116% of the long-term average), and the LKB had 62.3 inches (132% of average). Most rainfall occurred during the June-October wet season, especially in June and September, but dry season rainfall in May also contributed to above-average annual rainfall. Above-average rainfall in these months reflected nearly continuous rainfall throughout June 2017, a 2-day period in September associated with Hurricane Irma that accounted for more than half of that month's total rainfall, and an early beginning to the wet season during the latter half of May 2018. Wet season rainfall totaled 42.6 inches (135% of average) in the UKB and 44.5 inches (142% of average) in the LKB. Dry season rainfall totaled 15.4 inches (83% of average) in the UKB and 17.9 inches (111% of average) in the LKB.

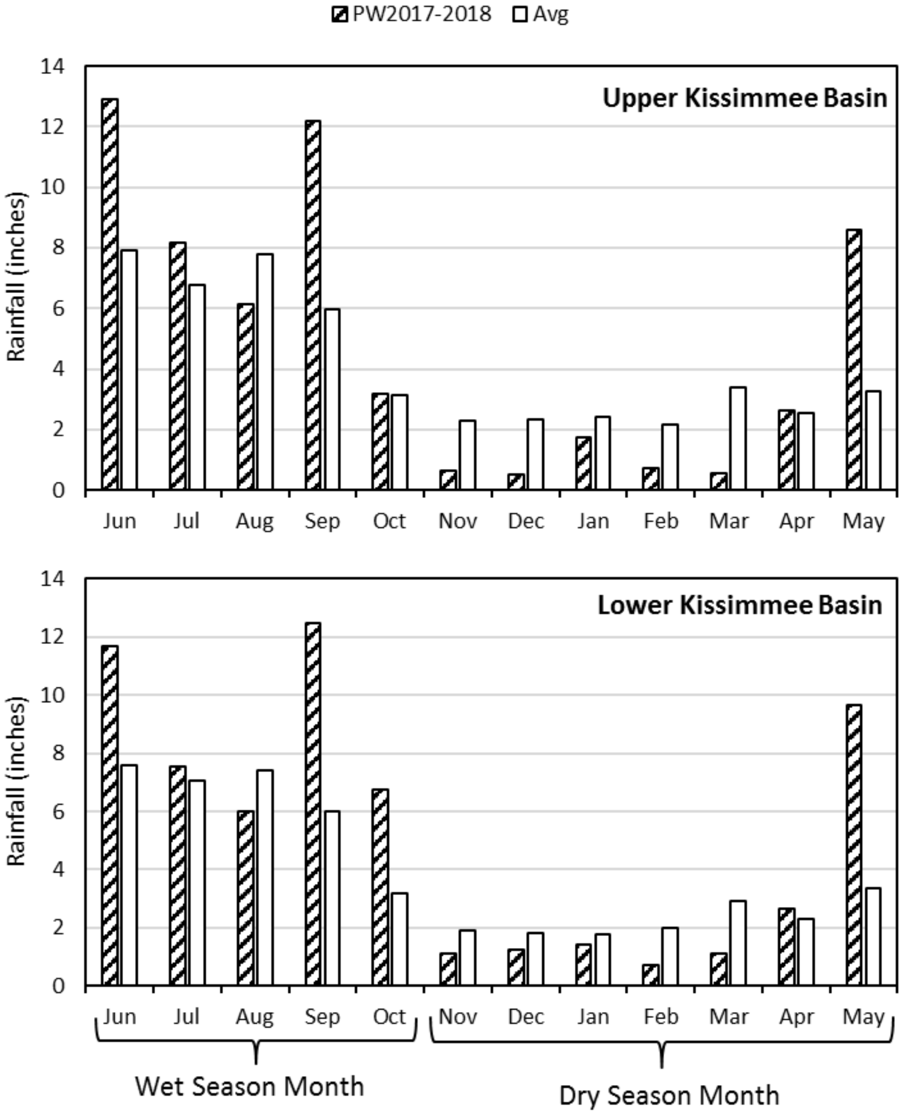


Figure 9-7. Monthly rainfall (in inches) for Planning Window 2017-2018 and average rainfall (1986–2015) in (top) the UKB and (bottom) the LKB.

OPERATIONAL REQUESTS AND OUTCOMES

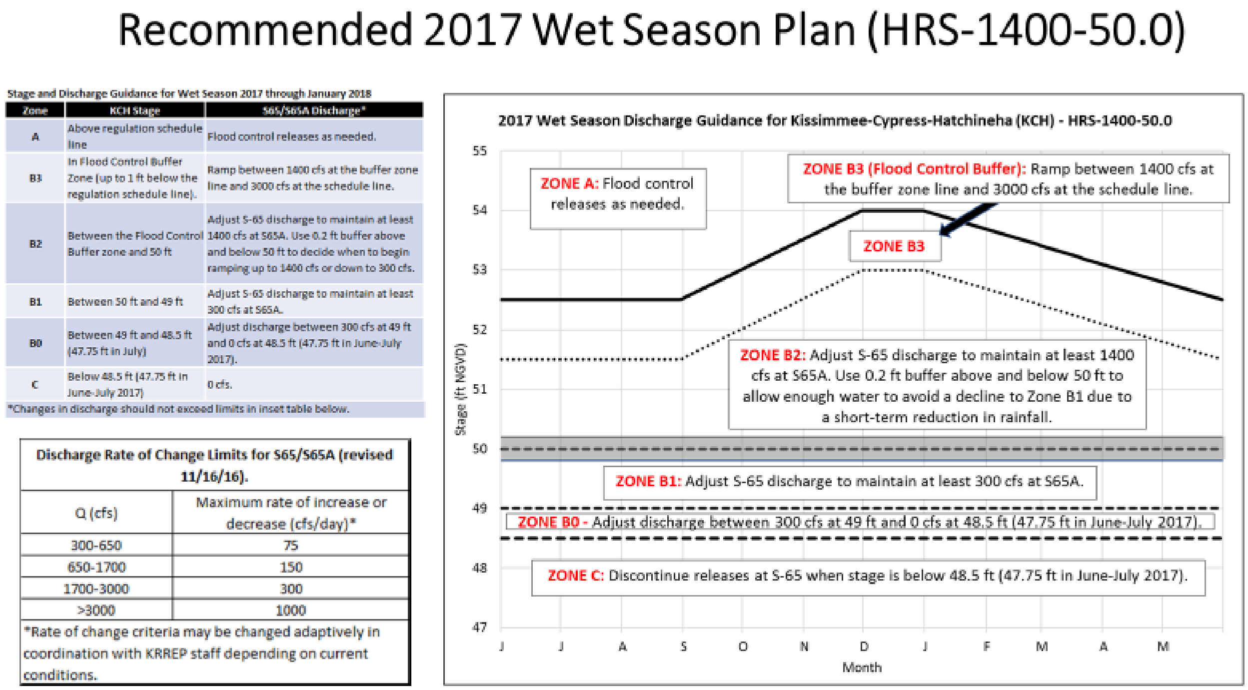
Seasonal Operational Planning

KRREP scientists collect input from partner agencies (SFWMD and USACE for KRRP, and from FWC, United States Fish and Wildlife Service [USFWS], and SFWMD for the KCOL) to develop wet and dry season recommendations that balance KRRP needs with other considerations within the Kissimmee Basin. Throughout this process, KRREP scientists work closely with the District's water managers to implement seasonal recommendations and coordinate Kissimmee Basin operations with other C&SF project purposes.

2017 Wet Season

KRREP Recommendations for 2017 Wet Season

- Implement the HRS-1400-50.0 discharge plan described below, which increases discharge slowly to 1,400 cfs as stage in the Headwaters Lakes approaches a 50.0-ft threshold, then holds 1,400 cfs except during flood control events unless lake stage declines below 50.0 ft. By request from the District's Water Management team, the plan uses the HRS regulation line to maximize potential storage in the Headwaters Lakes. The plan includes recommendations for limits on rates of change in discharge to KRRP to address recurring problems of DO crashes (bottom left table in **Figure 9-8**).



Recommended 2017 Wet Season Plan (HRS-1400-50.0)

Stage and Discharge Guidance for Wet Season 2017 through January 2018

Zone	KCH Stage	S65/S65A Discharge*
A	Above regulation schedule line	Flood control releases as needed.
B3	In Flood Control Buffer Zone (up to 1 ft below the regulation schedule line).	Ramp between 1400 cfs at the buffer zone line and 3000 cfs at the schedule line.
B2	Between the Flood Control Buffer zone and 50 ft	Adjust S-65 discharge to maintain at least 1400 cfs at S65A. Use 0.2 ft buffer above and below 50 ft to decide when to begin ramping up to 1400 cfs or down to 300 cfs.
B1	Between 50 ft and 49 ft	Adjust S-65 discharge to maintain at least 300 cfs at S65A.
B0	Between 49 ft and 48.5 ft (47.75 ft in July)	Adjust discharge between 300 cfs at 49 ft and 0 cfs at 48.5 ft (47.75 ft in June-July 2017).
C	Below 48.5 ft (47.75 ft in June-July 2017)	0 cfs.

*Changes in discharge should not exceed limits in inset table below.

Discharge Rate of Change Limits for S65/S65A (revised 11/16/16).

Q (cfs)	Maximum rate of increase or decrease (cfs/day)*
300-650	75
650-1700	150
1700-3000	300
>3000	1000

*Rate of change criteria may be changed adaptively in coordination with KRREP staff depending on current conditions.

2017 Wet Season Discharge Guidance for Kissimmee-Cypress-Hatchineha (KCH) - HRS-1400-50.0

ZONE A: Flood control releases as needed.

ZONE B3 (Flood Control Buffer): Ramp between 1400 cfs at the buffer zone line and 3000 cfs at the schedule line.

ZONE B2: Adjust S-65 discharge to maintain at least 1400 cfs at S65A. Use 0.2 ft buffer above and below 50 ft to allow enough water to avoid a decline to Zone B1 due to a short-term reduction in rainfall.

ZONE B1: Adjust S-65 discharge to maintain at least 300 cfs at S65A.

ZONE B0 - Adjust discharge between 300 cfs at 49 ft and 0 cfs at 48.5 ft (47.75 ft in June-July 2017).

ZONE C: Discontinue releases at S-65 when stage is below 48.5 ft (47.75 ft in June-July 2017).

Figure 9-8. The HRS-1400-50.0 discharge plan for wet season 2017. Inserted table specifies limits on rates of discharge increase and decrease at S-65 and S-65A. The plan uses the HRS regulation line. Source: KB-2017-Wet Season Planning Presentation (June 1, 2017).

USACE KRR Construction for 2017 Wet Season

- Requested by USACE to hold S-65A discharge < 1000 cfs “as often as possible”.

KCOL Considerations for 2017 Wet Season

- Manage ascension rates on East Lake Tohopekaliga, Lake Tohopekaliga, and the Headwaters Lakes to not exceed 0.5 ft per 14 days to benefit alligator and apple snail (*Pomacea paludosa*) reproduction, other lake-dependent wildlife, and Everglades snail kite nests remaining active into summer from the 2016-2017 nesting season.

The 1,400-cfs Discharge Plan for 2017 Wet Season

As in previous years, planning for the 2017 wet season included modeling of different water management alternatives to consider the likely tradeoffs among options. The plan that best met these objectives was the recommended HRS-1400-50.0 (**Figure 9-8**), which was based on plans developed in previous years to provide for more continuous inundation of the Kissimmee River floodplain while balancing concerns about low lake stages by linking discharge to lake stage (and therefore to rainfall). This operating plan had been implemented successfully during the 2015 wet season (June–October 2015). It was also recommended for implementation in the 2016 wet season but was superseded by the District’s non-standard emergency operations that attempted to hold as much water in the UKB to reduce flow to Lake Okeechobee and possibly the coastal estuaries. The 2017 wet season version of the plan differs from previous versions by using the regulation schedule line from the HRS to determine when flood control releases will be made (effectively increasing the potential storage in the Headwaters Lakes), widening the buffer zone from 0.25 ft to 1 ft for the transition from 1,400 cfs to flood control releases, and lowering the threshold stage to 50.0 ft for transitions from 300 cfs to and from 1,400 cfs. Using the HRS regulation schedule line was part of an attempt to test the HRS.

Because the Kissimmee River floodplain slopes to the south, sustained floodplain inundation almost fully depends on discharges from S-65 via S-65A (Anderson 2014). In past years of the Interim Period (2001–present), S-65 operations have tended to alternate (often multiple times per year) between brief periods of high discharge for flood control as stages in the Headwaters Lakes rose to or above the regulation line, followed by rapid reductions in discharge to avoid subsequent stage declines in the Headwaters Lakes. The undesirable effect of such operations for the Kissimmee River, clearly visible in stage/discharge hydrographs (e.g., **Figure 9-9**), was sudden inundation of the floodplain followed by rapid termination of flood events as discharge declined below river channel bankfull (approximately 1,400 cfs). The resulting pattern of intermittent periods of floodplain inundation followed by rapid drying (often within a time frame of weeks) was quite different from the single long, continuous flood event characteristic of the natural flood pulse that occurred seasonally in the pre-channelized system (Koebel et al. 2016). Such sudden increases in stage and the ensuing depth reductions on the Kissimmee River floodplain are unnatural, are contrary to restoration goals, interfere with fish reproduction and recruitment that depend on river channel/floodplain connectivity during the breeding season, and disrupt wading bird foraging on the floodplain, especially during the dry season (breeding season). During both the wet and dry seasons, such operations cause periods of intermittent inundation punctuated by rapid drydowns of the floodplain.

Discharge changes during the 2014 (WY2015) wet season can be used to illustrate this undesirable, intermittent wet/dry pattern and the potential for improvement of hydroperiod duration (Koebel et al. 2016). During the 2014 wet season, discharge was increased above full floodplain inundation (3,000 cfs) and reduced to within-channel levels 3 times over 88 days (July 12–October 7, 2014, in **Figure 9-9**). Some of the discharge occurred at high levels that have no known benefit for KRRP and actually may be harmful because of the resulting extreme depths. The total volume discharged during this interval was 344,960 ac-ft; a volume equivalent to a discharge of 1,400 cfs (above bankfull) for 124 consecutive days, suggesting more proactive avoidance of the regulation line before it is reached and less abrupt, reactive operations might reduce such undesirable patterns of flooding and drying. The HRS-1400-50.0 discharge plans change the timing of discharge so more of the discharge volume occurs at levels that are beneficial to the floodplain, while reducing the duration and frequency of (or eliminating) periods of below bankfull discharge to the extent possible given the rainfall that occurs in a given year. Overall, the plan has not been found to have a net negative effect on Headwaters Lakes stage; long term, modeling has shown that during wet years (which occur every 5 to 7 years), years of high stage in the Headwaters Lakes coincide with years of prolonged, continuous floodplain inundation.

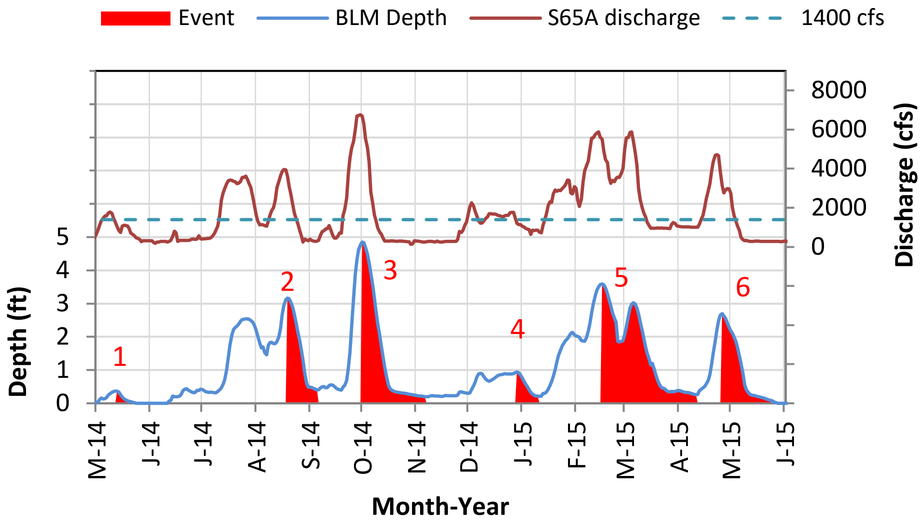


Figure 9-9. Large increases in S-65A discharge followed by decreases in discharge caused six discrete floodplain inundation and recession events during WY2015.

The HRS-1400-50.0 discharge plan is weather-driven in that it does not increase discharge until rainfall has caused lake water levels to rise to 50.0 ft and does not reduce discharge unless rainfall is insufficient to keep water levels above 50.0 ft. Discharge greater than 1,400 cfs occurs only if there is sufficient rainfall to raise lake stage to the buffer zone (Zone B3) or above the regulation schedule, necessitating flood control releases while in Zone A. The plan includes limits on the rate of discharge increase and decrease (as shown in the table insert of **Figure 9-8**). The range of discharges used in the plan are conservative relative to the hydrologic needs of restoration. The choice of 1,400 cfs as the discharge needed for floodplain inundation is based on estimated bankfull discharge (i.e., the discharge needed to fill and exceed the banks of the river channel) of 1,400 cfs in the pre-channelization Kissimmee River (Warne et al. 2000). The plan is also conservative in that it reduces discharge to 300 cfs, substantially lower than the mean minimum discharge (500 cfs) that occurred during the pre-channelization Reference Period (Anderson 2014), and in that the rates of change are faster than occurred in the pre-channelization system. The plan is a compromise between lake and river benefits; it was selected from several alternatives that differed primarily in the threshold elevation at which discharge would be increased from minimum flow (300 cfs) to 1,400 cfs. Modeling indicated the use of lower thresholds (e.g. 49.5 ft) allowed more water to be discharged from the Headwaters Lakes to the river and would increase the duration of discharge at or above 1,400 cfs, resulting in a longer duration of floodplain inundation. However, the use of lower stage thresholds resulted in lower stages in the Headwaters Lakes relative to higher thresholds. Conversely, raising the stage threshold results in higher mean stage in the Headwaters Lakes over the simulation period, but shortens periods of floodplain inundation. Thus, the threshold selected for the 2017 wet season was a compromise between Headwaters Lakes goals and KRRP goals, which demand slowly varying discharge without repeated, unnecessary reductions of discharge to below bankfull levels punctuated by brief high flow events separated by slow recessions.

The discharge plan is not intended to fully meet restoration targets for the Kissimmee River during the current, Interim Period. However, variants of a 1,400 cfs/50.0 ft discharge plan have been determined to improve on prior operations, moving toward better performance in a crucial aspect of the hydrologic requirements for restoration and floodplain inundation.

Ultimately, successful implementation of the HRS-1400-50.0, or any version of the discharge plan, depends on the operation of S-65A, which controls discharges to the Kissimmee River. This structure is operated to provide flood control in Pool A by maintaining the headwater stage (upstream of the structure) near 46.3 ft NGVD29. Because of the limited range of headwater stage fluctuation and the small surface area (C-38 in Pool A is only 250 ft wide), there is limited capacity to store local basin runoff. Consequently, even small rainfall events can necessitate a reduction in the inflow at S-65, an increase in the outflow at S-65A, or both to control rising water levels. For example, the volume of water equivalent to 1 inch of rainfall over the Pool A basin instantaneously transferred to Pool A could increase the stage by 4.5 ft if discharge was not adjusted. The lack of storage in Pool A will continue to pose a challenge for water management after the restoration project is completed.

2017 Wet Season Water Management Outcomes

HRS-1400-50.0 Discharge Plan. The HRS-1400-50.0 discharge plan (**Figure 9-8**) was implemented for the 2017 wet season. At the beginning of the wet season, stage in the Headwaters Lakes was below low pool and very small releases were made from S-65. Rainfall and runoff from the Pool A basin were enough to maintain discharge of at least 300 cfs at S-65A for most of June, and releases ceased at S-65 for approximately 2 weeks in the middle of the month. As Pool A basin runoff increased, S-65A discharge was increased to control rising water levels in Pool A; discharge peaked at 1,600 cfs and remained greater than 1,400 cfs for 4 days before being reduced to 300 cfs, marking the end of the first of two floodplain inundation events during the 2018 wet season.

Stage in the Headwaters Lakes rose to 50.0 ft NGVD29 on July 2. S-65A discharge was increased gradually for 52 days until it reached 1,400 cfs on August 22 and stage in the Headwaters Lakes had risen to 51.95 ft NGVD29. S-65A discharge remained greater than 1,400 cfs until November 8, providing the second period of floodplain inundation, which lasted 79 days. During September 10-11, Hurricane Irma passed northward over the Florida peninsula and west of the Kissimmee Basin. The resulting rainfall and runoff caused stage to rise in the Headwaters Lakes to 54 ft NGVD29 (the December high pool in the HRS) and a decision was made to return to the Interim Schedule high pool (52.5 feet). Discharge was increased to > 10,000 cfs for 2 weeks and reduced through October, then held at 1,400 cfs for 3 days before being reduced to 300-500 cfs, where it remained for most of the remainder of the dry season. The reduction occurred when stage in the Headwaters Lakes was 51.84 ft NGVD29 on November 8, well above the 50.0 ft NGVD29 threshold in the plan for decreasing discharge to 300 cfs. Despite the discharge reductions, the Headwaters Lakes continued to recede, though much more slowly into the 2017-2018 dry season.

The two Kissimmee River floodplain inundation events during the 2017 wet season were quite different (**Figure 9-10B**). The first was due to increases in S-65A discharge caused by runoff from the Pool A basin and limited storage within the pool (i.e., all runoff had to be passed through S-65A). It resulted in a brief inundation event with water depth > 0.1 ft for 18 days (June 15–July 2) and a maximum water depth of 0.8 ft. The second was due to the implementation of the 1,400-cfs discharge plan and was sustained in part by rainfall from Hurricane Irma. It resulted in a BLM depth increase to 4.7 ft and was > 1 ft for 63 days (September 10–November 11).

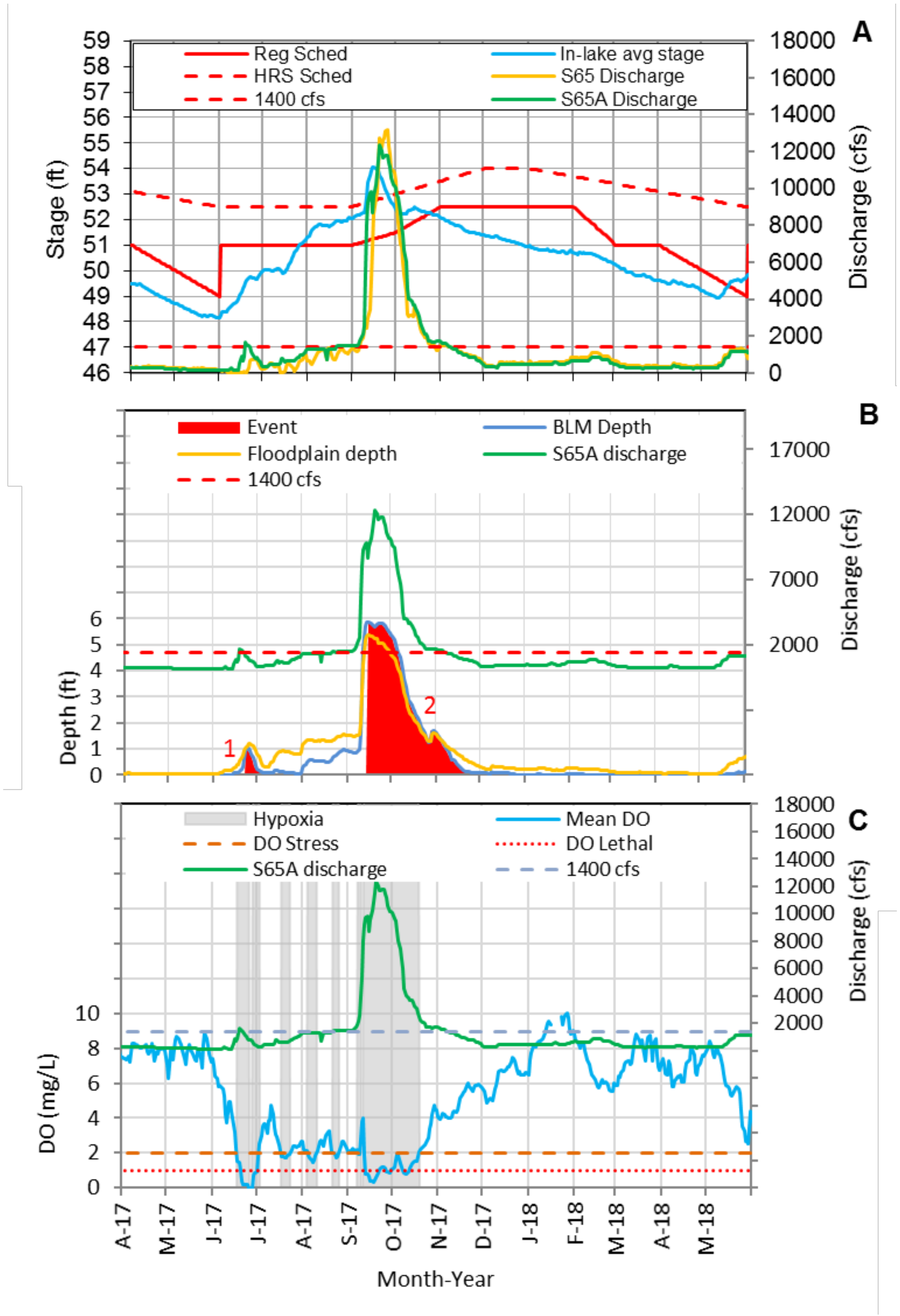


Figure 9-10. (A) Regulation schedule, HRS regulation schedule, lake stage, and discharge from the Headwaters Lakes; (B) floodplain depth and BLM depth at five stations (PC52, PC55, PC53, PC44, and PC42) in the northern floodplain where BLM occurred pre-channelization and is expected to reestablish after restoration is completed in relation to mean daily discharge at S-65A during WY2018; and (C) mean daily DO (calculated from 15-minute measurements) in the river channel at PC33 and PC62, and discharge at S-65A. Red numbers in Panel B identify two floodplain flood events that are described in the text. See **Figure 9-6** for locations of hydrologic monitoring sites and the *Kissimmee River Restoration Evaluation Program* section's *Hydrology* subsection for more information.

Wet Season Dissolved Oxygen. During the 2017 wet season, the Kissimmee River was anoxic (DO concentration less than 1 mg/L) for portions of June and September; intermittent hypoxia (DO less than 2 mg/L) occurred during the intervening period (**Figure 9-10C**). The first anoxic period likely caused a confirmed fish kill. The second anoxic period followed the rapid increase in discharge associated with Hurricane Irma. Further details are provided in the *Dissolved Oxygen* subsection of the *Kissimmee River Restoration Evaluation Program* section.

Ascension Rates. The well above average rainfall in June (**Figure 9-7**) caused water levels to begin rising at the beginning of the 2017 wet season, from the low pool stages in East Lake Tohopekaliga (**Figure 9-11A**) and Lake Tohopekaliga (**Figure 9-11B**) and from 0.85 ft below the low pool stage in the Headwaters Lakes (**Figure 9-12B**). Because of the rapid stage rise, discharge was increased from East Lake Tohopekaliga and Lake Tohopekaliga, as requested by FWC and USFWS in prior years to slow the rate of stage ascension. Although increased to the maximum possible discharge under the conditions at that time, the increase in discharge was not enough to constrain ascension rates in East Lake Tohopekaliga and Lake Tohopekaliga. Both lakes had 16 exceedances of the preferred rate of 0.5 ft per 14 days during the June 1–August 15 window. Ascension rates were calculated daily as the difference between the current and 14-day antecedent stage.

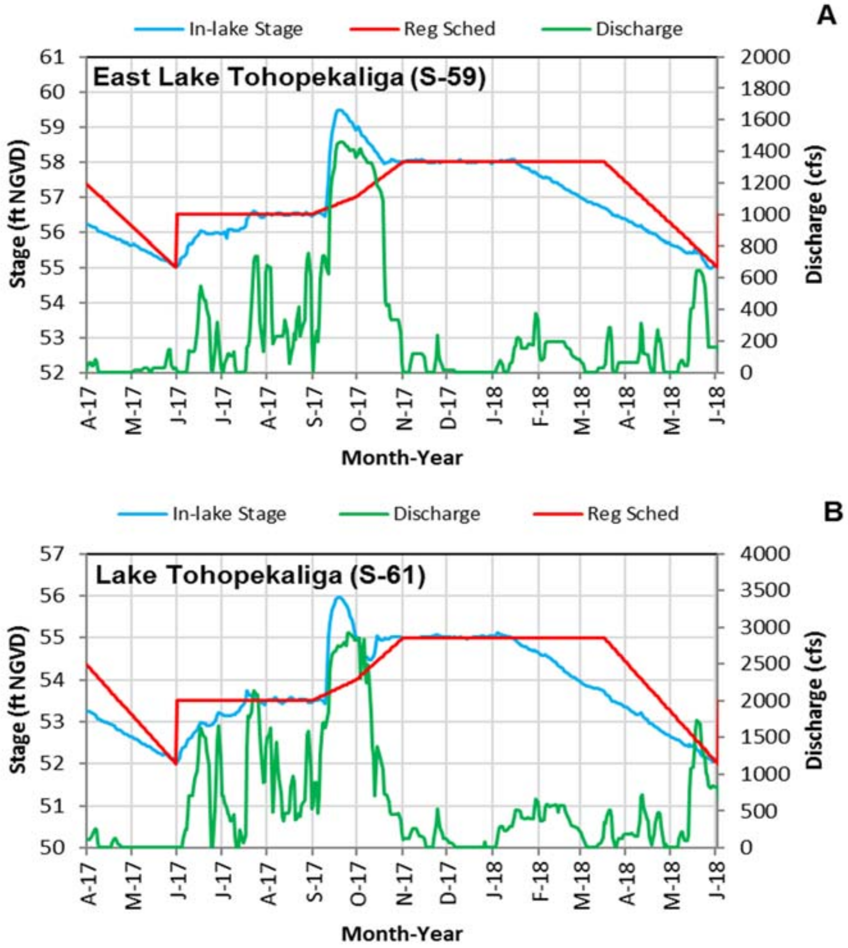


Figure 9-11. Regulation schedule, stage, and discharge for (A) East Lake Tohopekaliga and (B) Lake Tohopekaliga during WY2018 and April 2017 and May 2018.

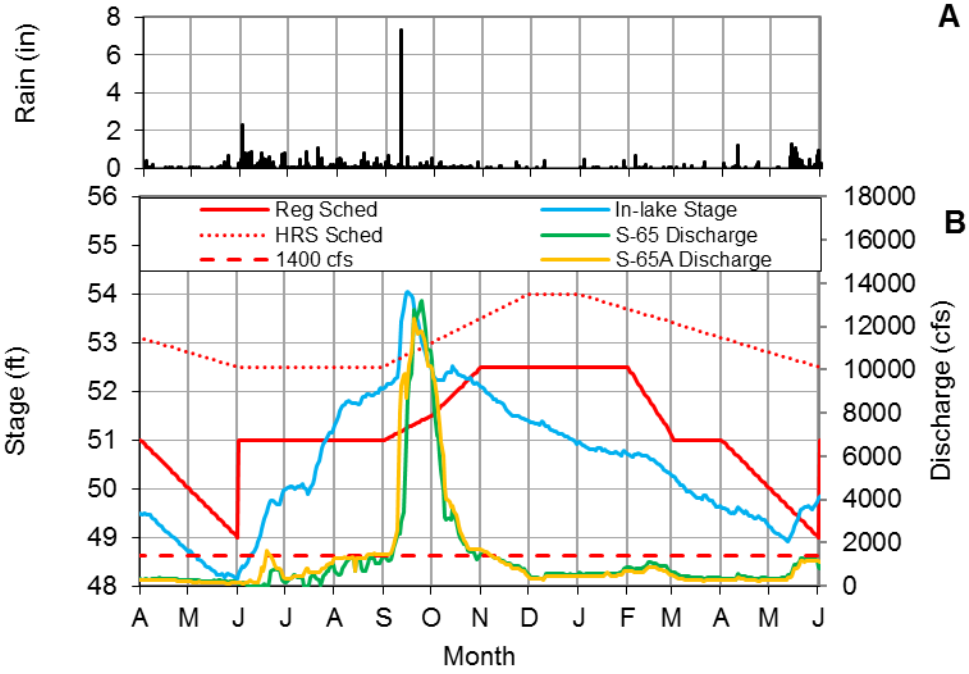


Figure 9-12. (A) Basin rainfall and (B) regulation schedule and stage in the Headwaters Lakes and discharge from the Headwaters Lakes at S-65 and at S-65A for WY2018 and April 2017 and May 2018.

The Headwaters Lakes had nearly triple the number of ascension rate exceedances as East Lake Tohopekaliga or Lake Tohopekaliga. The highest number of exceedances typically is expected in the Headwaters Lakes due to the combination of releases from S-61 (**Figure 9-11B**) to control ascension upstream in Lake Tohopekaliga, limits on rates of discharge increase at S-65/S-65A to protect the Kissimmee River (see the *Hydrology* subsection in the *Kissimmee River Restoration Evaluation Program* section), and prioritization of operations among the lakes.

2017-2018 Dry Season

FWC Requests for 2017-2018 Dry Season (Received November 20, 2017)

- Start recession in the Headwaters Lakes on January 1, 2018.
- Start recessions on Lake Tohopekaliga and East Lake Tohopekaliga on January 15, 2018.
- Recede to low pools on all lakes on May 31, 2018.
- Recession rates not to exceed 0.2 ft/week.

USFWS Requests for 2017-2018 Dry Season (Received November 30, 2017)

- Begin recessions in Lake Tohopekaliga, East Lake Tohopekaliga, and the Headwaters Lakes in January 2018.
- Recession rate in all of the abovementioned lakes between 0.15 and 0.20 ft/week.
- Recession rates not to exceed 0.2 ft/week.

KRREP Recommendations for 2017-2018 Dry Season

- Use limits on rates of change in discharge at S-65/S-65A.

USACE Requests to Facilitate Construction in 2017-2018 Dry Season

- Subject to other operational demands and to the extent possible, keep discharge below 1,000 cfs "as often as possible" to facilitate construction backfilling of the C-38 canal for Reach 2 construction.

2017-2018 Dry Season Water Management Outcomes

During the dry season, East Lake Tohopekaliga and Lake Tohopekaliga had slow, steady stage recessions that began with stage at the regulation schedule on January 15 and ended at the low pool of the schedule on June 1 (**Figure 9-11**). Both lakes had mean daily recession rates equivalent to 0.14 ft/week, not meaningfully lower than the preferred range requested by the USFWS. In the Headwaters Lakes, stage had been declining since October, with the maintenance of discharge to the Kissimmee River, and continued until May 13, when it was effectively ended by high rainfall due to an early start of wet season conditions and inflow from Lake Tohopekaliga (**Figure 9-12**). The recession rate between January 1 (the requested start date) and May 13 was equivalent to 0.11 ft/week.

Discharge at S-65A was reduced to approximately 300 cfs in early December and remained at low to moderate levels (average of 400 cfs); it did not exceed 1,150 cfs for the remainder of the dry season. Less than 1,400 cfs discharge is confined to the river channel and does not increase BLM mean depth (**Figure 9-10B**).

Discharge was less than 1,000 cfs from November 17, 2017 to May 20, 2018, providing 185 days of the flow conditions requested for construction.

WY2018 Water Management Summary and Conclusions

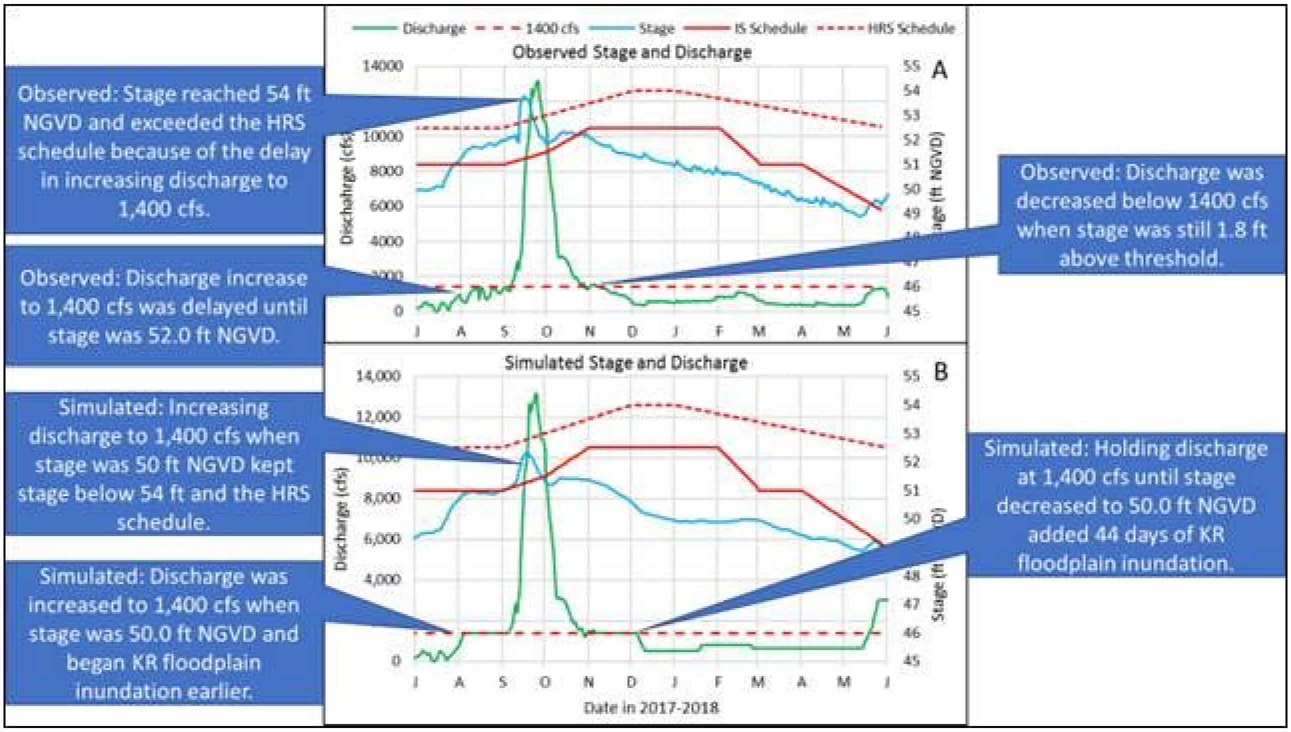
2017 Wet Season

The HRS-1400-50.0 was implemented in the 2017 wet season to guide discharge operations at S-65/S-65A. It is like a discharge plan named IS-14-50.5, which was implemented during the 2015 wet season and was recommended but not implemented for the 2016 wet season due to emergency operations. The HRS-1400-50.0 differs from the earlier plan by a) lowering the stage threshold by 0.5 ft to 50.0 ft NGVD29 to transition between 300 cfs and 1,400 cfs; b) raising the threshold for beginning flood control releases to the HRS regulation schedule line; and c) widening the buffer zone for increasing or decreasing discharge between 1,400 cfs and flood control releases. These changes were intended to increase the ability to maintain discharge of at least 1,400 cfs, thus providing longer and more continuous periods of floodplain inundation than had occurred in the post-channelized period prior to their use.

Implementation of the HRS-1400-50.0 during the 2017 wet season resulted in a single inundation event that lasted 79 days. Despite adjustments to the plan to provide longer periods of inundation and the rainfall from Hurricane Irma, the single inundation event produced by the HRS-1400-50.0 was only 4 days longer than the single inundation event in the 2015 wet season that resulted from IS-14-50.5 (August 13-October 26, 2017). The only slight improvement of the HRS-1400-50.0 may be because it was not strictly implemented; the stage thresholds for transition from 300 to 1,400 cfs and back were implemented almost 2 ft higher than what were stated in the plan. The delay in increasing discharge may have reflected a desire to test the HRS by allowing stage to rise in the Headwaters Lakes; the early decrease in discharge below 1,400 cfs reflected concerns about being able to maintain discharge through the dry season.

Strict implementation of the HRS-1400-50.0 during the 2017 wet season was simulated with a simple spreadsheet tool that allows the user to change daily discharge values and uses stage-area relationships to calculate the resulting change in stage. In the simulation, discharge was increased to 1,400 cfs when stage in the Headwaters Lakes had risen to 50.0 ft NGVD29 and continued at 1,400 cfs until stage in the lakes had decreased to 50.0 ft NGVD29 (**Figure 9-13**). The simulation shows that period of inundation would have been longer by 123 days (August 5 to December 5); 44 days longer than occurred in the 2017 wet season. Much of this increase was due to the extension of the plan into the dry season and occurred in the

August-February target window for inundation. This suggests future implementations should continue into the dry season. One consequence of the earlier increase in discharge to 1,400 cfs was that stage did not rise above the HRS regulation schedule or reach 54 ft as it did in observed data for the 2017 wet season. This demonstrates a benefit of increasing discharge earlier in the wet season.



Observed: Stage reached 54 ft NGVD and exceeded the HRS schedule because of the delay in increasing discharge to 1,400 cfs.

Observed: Discharge increase to 1,400 cfs was delayed until stage was 52.0 ft NGVD.

Observed: Discharge was decreased below 1400 cfs when stage was still 1.8 ft above threshold.

Simulated: Increasing discharge to 1,400 cfs when stage was 50 ft NGVD kept stage below 54 ft and the HRS schedule.

Simulated: Discharge was increased to 1,400 cfs when stage was 50.0 ft NGVD and began KR floodplain inundation earlier.

Simulated: Holding discharge at 1,400 cfs until stage decreased to 50.0 ft NGVD added 44 days of KR floodplain inundation.

Figure 9-13 Comparison of observed (A) and simulated (B) stage (blue line) and discharge (green line) in the Headwaters Lakes during June 2017–May 2018. Actual operations (observed values) resulted in one event of discharge greater than 1,400 cfs –for 79 days (August 22–November 8, 2017). Simulation of operations that maintained discharge at 1,400 cfs when stage was above 50.0 ft resulted in a single event for 123 days (August 5–December 5, 2017). Interim regulation schedule (IS), HRS, and 1,400-cfs lines are provided for reference.

Discharge plans, like HRS-1400-50.0, show promise for improving the duration and continuity of floodplain inundation; however, they are not expected to fully meet the hydrologic restoration criteria described in the *Hydrology* subsection of the *Kissimmee River Restoration Evaluation Program* section. Such plans should continue to be implemented because inundation of the Kissimmee River floodplain is almost fully dependent on discharge (Anderson 2014). Future implementation should incorporate refinements to improve hydrologic and ecological performance. First, 1,400 cfs is an estimate of the bankfull discharge and just begins to inundate the floodplain. A flow rate of 1,400 cfs did not maintain water depth of 1 ft at the BLM sites during the 2015 wet season (Koebel et al. 2017) or the 2017 wet season (**Figure 9-10B**). How much discharge will need to be increased will have to be determined adaptively during future plan implementation. A second refinement is extension of the plan into the dry season. During the pre-channelization period, inundation could occur year-round and frequently occurred well into the dry season. Simulation of the 2017 wet season showed inundation could be extended by about a month into the dry season (**Figure 9-13**). A third refinement is to lower the threshold stage for increasing discharge. The plan for the HRS-1400-50.0 used a threshold 0.5 ft lower than the one used in the IS-14-50.5, but in implementation, the recommended threshold was not used. Plans have been modeled that used stage thresholds as low as 49.5 ft that produced satisfactory outcomes for KRRP flood pulse and Headwaters Lake stages. Finally, the plans need to be consistently and aggressively implemented.

During the 2017 wet season, ascension rates exceeded the 0.5 ft per 14 days threshold on 16 days in East Lake Tohopekaliga, 16 days in Lake Tohopekaliga, and 44 days in the Headwaters Lakes. As reported in Chapter 9 of the 2016 SFER – Volume I (Koebel et al. 2016), attempts to control early wet season ascension rates can—and often will—be overwhelmed by rainfall events; as shown earlier, ascension rates exceeding 0.5 ft using the 14-day difference method occurred frequently prior to regulation. A higher frequency of exceedances is expected in all lakes, but particularly in the Headwaters Lakes because of interactions between East Lake Tohopekaliga and Lake Tohopekaliga and the effects of discharge from those lakes on stage in the Headwaters Lakes. Inflow into the Headwaters Lakes is increased by efforts to reduce ascension rates upstream in East Lake Tohopekaliga and Lake Tohopekaliga (S-59 and S-61, respectively) as well as by limits on rates of discharge increase downstream to protect KRRP. This finding illustrates the strong potential for operational conflicts among these three water bodies, complicating the implementation of lake stage target requests, including both ascension and recession rates.

2017-2018 Dry Season

Although the 2017-2018 dry season, like the previous dry season, had below average rainfall, the requested recession rate of 0.2 ft/week was exceeded on 55 days in East Lake Tohopekaliga, 38 days in Lake Tohopekaliga, and 40 days in the Headwaters Lakes. The inability to meet the requested targets under extremely favorable (dry) conditions highlights the unlikelihood of meeting these target rates under more moderate (average rainfall) conditions. After discharge at S-65A was decreased to approximately 300 cfs in early December, low to moderate levels (average of 400 cfs) were needed to lower stage to the low pool. Consequently, flow was confined to the river channel and did not increase BLM mean depth in the floodplain (**Figure 9-10B**). The dry conditions resulted in S-65/S-65A discharge remaining below 1,000 cfs for 185 days.

KISSIMMEE RIVER RESTORATION EVALUATION PROGRAM

A major component of the KRRP is assessment of restoration success by the Kissimmee River Restoration Evaluation Program (KRREP), a comprehensive ecological monitoring program (Bousquin et al. 2005, Williams et al. 2007, Koebel and Bousquin 2014) mandated and designed to evaluate the ongoing status and ultimate success of the KRRP in meeting its environmental goals. Restoration evaluation was identified as SFWMD's responsibility in its cost-share agreement with USACE for KRRP (Department of the Army and SFWMD 1994). Initiation of the KRREP in the 1990s represented a pioneering effort to use scientific data from a set of rigorous and statistically valid monitoring studies to evaluate the success of one of the largest floodplain-river restoration projects in the world. Success is partly based on 25 hydrologic, biotic, and abiotic performance measures (Anderson et al. 2005) used to track project success and evaluate how well the project meets its goal of re-establishment of ecological integrity to the Kissimmee River and floodplain (Koebel and Bousquin 2014). Ecological integrity is defined as a reestablished floodplain-river ecosystem "capable of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region" (Karr and Dudley 1981). Targets for the performance measures, called restoration expectations, are based on estimated conditions in the pre-channelized system (reference conditions) and have undergone extensive external peer review. Most KRREP studies use a before-after-control impact paired series (BACIPS; Osenberg et al. 2006) design, in which data are collected before and after KRRP construction, over the same period in areas in which construction will take place (impact areas), and in areas where the system is not being physically altered by KRRP (control areas). Trends and results from these evaluations are reported in several ways, including peer reviewed and SFWMD technical publications, scientific conferences, and annual reports. Full realization of some aspects of the restoration expectations, particularly those related to floodplain responses in specific portions of the floodplain, are tied to removal of the S-65C water control structure, which occurred in June 2017, and HRS implementation in 2020. However, targeted adaptive water management in the Interim Period prior to project completion can move parts of completed phases of the project in the direction required by project goals. Although final evaluations of project success will occur after all construction components are in place, the ecological and hydrologic responses being documented prior to project completion are used to evaluate the ongoing status of ecosystem recovery and to guide adaptive management of the system. Monitoring for ecological evaluation will continue for at least 5 years after construction is complete or until ecological responses have stabilized (USACE 1991).

Post-construction monitoring continued in the Phase I restoration area in WY2018, and the results are presented here. Many of the Phase I studies, which involve collection and analysis of data on hydrology, geomorphology, water quality, river channel and floodplain vegetation, aquatic invertebrates, herpetofauna, fish, and birds, have already documented changes consistent with those predicted by the expectations developed for the KRREP (Anderson et al. 2005), particularly in the river channel, albeit with responses of hydrology and vegetation on the floodplain lagging substantially behind (see the *Hydrology* subsection; Anderson 2014, Spencer and Bousquin 2014). This is due to the difficulty of achieving sustained floodplain inundation in the Interim Period. A comprehensive update of initial responses to Phase I reconstruction was first published in Chapter 11 of the 2005 SFER – Volume I (Williams et al. 2005b), with updates using newly available monitoring data published annually in subsequent SFERs. The combined results for a group of interrelated river channel studies were presented in Chapter 11 of the 2006 SFER – Volume I (Williams et al. 2006) and in Bousquin et al. (2007). In addition, nine papers on interim responses were published in a special issue of the journal *Restoration Ecology* in May 2014. **Table 9-3** provides a directory of KRREP monitoring study updates presented in the SFER since 2005.

To contain costs, most KRREP studies do not collect data continuously, with most studies active for 2 to 5 years during the Baseline (pre-restoration), Interim, and/or Post-construction response periods. The Interim Period for KRREP evaluations of the Phase I area is defined as the years between completion of Phase I construction (2001) and completion of remaining construction phases and implementation of the HRS. During the Interim Period, the river's physical and hydrologic characteristics are only partially reestablished. Therefore, although substantial improvements can be made in the Interim Period by appropriate water management, the full array of hydrologic management options is not available. Therefore, the hydrologic conditions expected to lead to full restoration of the river and floodplain are not yet in place.

Only studies that collected new data in WY2018 are updated in this section. New results from studies of floodplain hydrology, DO, floodplain vegetation, fish populations and wading birds and waterfowl document the status of these ecosystem components. Where applicable, results are evaluated in relation to the associated restoration expectations.

Table 9-3 Directory of KRREP Phase I restoration response monitoring study updates in the 2005–2019 SFERs. [a]

KRREP Monitoring Study or Project	Expectation Number	Beginning Page Number in 2005–2019 SFERs – Volume I														
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Kissimmee River Restoration Evaluation Program		11-8	11-37	11-22	11-28	11-36	11-26	11-25	9-16	9-19	9-20	9-22	9-27	9-29	9-27	9-27
Hydrology																
Stage-discharge relationships	None	11-20														
Continuous river channel flow	1	**11-18**				**11-39**	**11-29**	**11-29**	**9-20**	**9-23**	**9-22**	**9-26**				
Variability of flow	2					**11-40**	**11-31**	**11-32**	**9-20**	**9-23**	**9-23**	**9-28**				
Stage hydrograph	3	**11-22**				**11-41**	**11-32**	**11-33**	**9-21**	**9-24**	**9-24**	**9-30**	**9-37**	**9-38**	**9-37**	**9-37**
Stage recession rate	4	**11-23**	11-23	11-16	11-19	**11-42**	**11-34**	**11-35**	**9-24**	**9-27**	**9-28**	**9-33**	**9-41**	**9-42**	**9-41**	**9-41**
Flow velocity	5	**11-25**					**11-35**	**11-37**	**9-24**							
Broadleaf marsh indicator	None					11-43						9-33	9-37			
Geomorphology																
River bed deposits	6	**11-26**						**11-70**								
Sandbar formation	7	**11-26**						**11-70**								
Channel monitoring	None					11-54		11-68								
Sediment transport	None							11-71								
Floodplain processes	None							11-72								
Dissolved Oxygen	8	**11-28**	**11-44**	**11-25**	**11-28**	**11-45**	**11-36**	**11-38**		**9-27**	**9-30**	**9-36**	**9-45**	**9-47**	**9-45**	**9-45**
River Channel Metabolism	None				11-35											
Phosphorus	None	11-33	11-52	11-30	11-32	11-51	11-43	11-43	9-25	9-31	9-34	9-40	9-50			
Turbidity	9	**11-30**	**11-48**	**11-27**												
Periphyton	None	11-46														
River Channel Vegetation																
Width of littoral vegetation beds	10	**11-36**				**11-59**										
River channel plant community structure	11	**11-37**				**11-59**										
Floodplain Vegetation																
Areal coverage of floodplain wetlands	12	**11-39**			**11-35**			**11-47**			**9-42**	**9-50**				**9-55**
Areal coverage of broadleaf marsh	13	11-40			**11-35**			**11-47**			**9-43**	**9-51**				**9-56**
Areal coverage of wet prairie	14	11-40			**11-35**			**11-47**			**9-43**	**9-51**				**9-56**

Table 9.3. Continued.

KRREP Monitoring Study or Project	Expectation Number	Beginning Page Number in 2005–2017 SFERs – Volume I														
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Invertebrates																
Macroinvertebrate drift composition	15	**11-45**	11-57													
Snag invertebrate community structure	16	**11-46**	11-55			11-62										
Aquatic invertebrate community structure in broadleaf marsh	17		11-57													
Benthic invertebrate community structure	18	**11-45**	11-58			11-62										
Native and nonnative bivalves	None							11-52								
Fish																
Impact of hypoxic events on largemouth bass and bluegill	None															9-58
Herpetofauna																
Floodplain reptiles and amphibians	19	11-48	Response data will be collected after implementation of the Headwaters Regulation Schedule (HRS).								9-47					
Floodplain amphibian reproduction and development	20	11-48	Response data will be collected after implementation of the HRS								9-47					
Fish Communities																
Small fishes in floodplain marshes	21	11-50	Response data will be collected after implementation of the HRS.													
River channel fish community structure	22	11-52	**11-59**			**11-66**			**9-29**							
Mercury in fish	None					11-20										
Floodplain fish community composition	23	11-50	Response data will be collected after implementation of the HRS.													
Birds																
Wading bird abundance	24	**11-58**	**11-71**	**11-32**	**11-44**	**11-72**	**11-50**		**9-36**	**9-41**	**9-53**	**9-57**	**9-51**	**9-55**	**9-57**	**9-60**
Waterfowl	25		**11-67**	**11-35**		**11-73**	**11-52**		**9-37**	**9-42**	**9-55**	**9-59**	**9-54**	**9-57**	**9-59**	**9-64**
Shore birds	None	11-57														
Wading bird nesting	None		11-68		11-40	11-72	11-47		9-33	9-38	9-47	9-53	9-56	9-51	9-53	9-66
Wading bird and waterfowl prey availability	None														9-62	
Threatened and Endangered Species	None	11-60														

a. Bolded page numbers indicate a major update in reference to the status of a restoration expectation (performance measure)

HYDROLOGY

Reestablishment of pre-channelization hydrologic characteristics will be the crucial drivers for restoration of the Kissimmee River and its floodplain by the KRRP. Restoration is to be accomplished by reconstruction of the physical habitat template, reestablishment of lost hydrologic characteristics, and implementation of adaptive water management operations guided by the results of hydrologic studies conducted by the KRREP. The key hydrologic characteristics of the ecosystem were identified in five restoration criteria in USACE (1991). The criteria define the essential hydrologic drivers needed to achieve restoration of the habitat and ecological integrity of the river-floodplain ecosystem. Meeting the hydrologic criteria is essential for achieving ecological integrity, which is identified as the project goal in the federal project documentation (USACE 1991, 1996). Reestablishment of pre-channelization hydrology is intended to ensure the project addresses the level of the ecosystem rather than individual taxa (Bousquin et al. 2005). The project documentation also requires monitoring and analysis of an array of specific biotic and abiotic ecosystem components to evaluate their responses to reestablished physical and hydrologic characteristics of the ecosystem (USACE 1991, 1996, Koebel and Bousquin 2014).

The hydrologic restoration criteria were expressed as five restoration expectations (performance measures) for evaluation of the status and ultimate success of the KRRP in terms of reestablished hydrology (Anderson et al. 2005). The hydrologic expectations use long periods of stage and discharge data to characterize pre-channelization hydrology (reference conditions) in terms of the magnitude, frequency, duration, timing, and rates of change of the hydrologic variables, and the expectations form the basis for expected future conditions of the restored system (Anderson et al. 2005). The hydrologic expectations have been evaluated annually since 2005 to assess restoration progress (see 2005–2018 SFERs – Volume I [Williams et al. 2005b, 2006, 2007, Bousquin et al. 2008, 2009, Jones et al. 2010, 2011, 2012, 2013, 2014, Cheek et al. 2015, Koebel et al. 2016, 2017, 2018]; and Anderson [2014] for examples of past hydrologic evaluations). These evaluations have shown that while conditions in the Phase I area have improved in the Interim Period for some hydrologic criteria when compared with the channelized Baseline Period (e.g., more continuous flow in the river channel; longer, albeit intermittent periods of floodplain inundation), hydrologic conditions in the Interim Period are neither meeting the restoration expectations nor showing a trend of improvement over time (Anderson 2014).

Meeting or moving toward the hydrologic targets depends on rainfall as well as appropriate water management to make the best use of available water. Operations in the 17-year Interim Period thus far have not been focused exclusively on improving hydrologic conditions for the Kissimmee River and floodplain. During the 2017 wet season, a discharge plan was recommended to improve floodplain inundation and recession events while balancing the effects on stage in the Headwaters Lakes. The 2017 discharge plan recommended maintaining at least 1,400 cfs (an estimate of the bankfull discharge of the Kissimmee River) when stage in the Headwaters Lakes was above 50.0 ft. Details of the plan and its use during the 2017 wet season are described in the *Kissimmee Basin Hydrologic Conditions and Water Management in Water Year 2018* section earlier in this chapter.

A challenge in past evaluations of the hydrologic criteria and development of the expectations was that the targets in the original hydrologic criteria were not necessarily stated in terms that could be readily translated into operational actions for practical recommendations and implementation. For example, a statement that flows should be reestablished comparable to pre-channelization conditions requires considerable analysis of historical flows to determine the reference condition and a target value, and evaluations comparing current to baseline and reference conditions. In addition, to make water management recommendations during the Interim Period, hydrologic goals must be stated and quantified in measurable operational terms (i.e., in terms of discharge and stage targets).

To meet these needs, changes are being made to the 2005 expectations and analysis methods to define additional metrics that can be used to better guide adaptive water management operations during the Interim Period as well as after the HRS is implemented when the project is completed, while retaining clear linkages with the original hydrologic criteria. The changes include realignment of the expectations with the original hydrologic criteria and addition of new metrics to more fully represent the original criteria. Changes are based on new analysis of data from the Reference (pre-channelization) and Interim (current) periods and incorporate a better understanding of the hydraulics of the system (e.g., the extent of the backwater effect from the current downstream structure) gained over the 17 years of system operation and analysis work since the Interim Period began in WY2002. This reorganization of the hydrologic expectations is meant to group metrics more logically and does not change their scope or the pre-channelization hydrologic criteria that were the source of the expectations. Only the metrics and/or methods being used to evaluate them are being modified. Modifications of the expectations have been ongoing and will be completed in Calendar Year (CY) 2019. Table 9-5 in 2016 SFER – Volume I, Chapter 9 (Koebel et al. 2016) provides a crosswalk between current and prior evaluation methodology.

This year's *Hydrology* section, as it did in the previous three years, focuses on Expectations 3 (hydroperiod) and 4 (recession events), which have been especially challenging to address operationally in the Interim Period. The section begins with a summary of the relationship of flood events to discharge and hydroperiod, especially in relation to the requirements of BLM, an important type of wetland that historically occurred in the Kissimmee River floodplain, and stage recession events using the same information used to guide development of Expectations 3 and 4. The section includes statements of each expectation; summarizes calculations of targets for the expectations using data from the Reference Period (WY1932–WY1962), conditions in the Baseline (regulated) Period (WY1972–WY1999) when the C-38 canal was in place; and evaluates response in the post-Phase I construction Interim Period (WY2002–WY2018) since Phase I completion but prior to completion of construction and implantation of the HRS. It concludes with recommendations for changes in discharge management that can improve performance for these expectations during the remainder of the Interim Period.

Flood Pulse, Hydroperiod, and Recession Event Background

Fluctuation of inflow resulting in seasonal inundation of floodplains (called a flood pulse) is the dominant force organizing the habitat of floodplain-river ecosystems such as the Kissimmee River (Junk et al. 1989, Toth et al. 2002, Winemiller et al. 2014). Many characteristics of the historical ecosystem depended on the flood pulse, including floodplain wetlands and the populations of fish, wading birds and waterfowl, and numerous associated species and assemblages (USACE 1991, USFWS 1991, Toth et al. 2002). The flood pulse concept is embedded in the general literature of river-floodplain ecology as well as the KRRP hydrologic criteria, especially Criterion 1 (variable discharge comparable to pre-channelization records), Criterion 2 (seasonal and annual variability of floodplain inundation), and Criterion 3 (water level recession rate in the floodplain) (Table 9-5 in Chapter 9 of the 2016 SFER – Volume 1 [Koebel et al. 2016]; USACE 1991). The following subsection provides background on floodplain inundation used to develop Expectations 3 and 4.

Floodplain hydroperiod requirements are based on the requirements of BLM, the most prevalent wetland plant community in the Kissimmee River floodplain prior to regulation, covering approximately half of the floodplain's area (Spencer and Bousquin 2014). The BLM community is dominated by *Pontederia cordata*, *Sagittaria lancifolia*, or a mixture of both species, and may include substantial cover of the shrub *Cephalanthus occidentalis*. BLM is known to have long hydroperiod requirements (Kushlan 1990, Toth 2010, Spencer and Bousquin 2014), estimated at > 200 days of inundation per year. **Figure 9-14** shows the range of hydroperiods reported in the literature for BLM and another major wetland type occurring in the Kissimmee River floodplain.

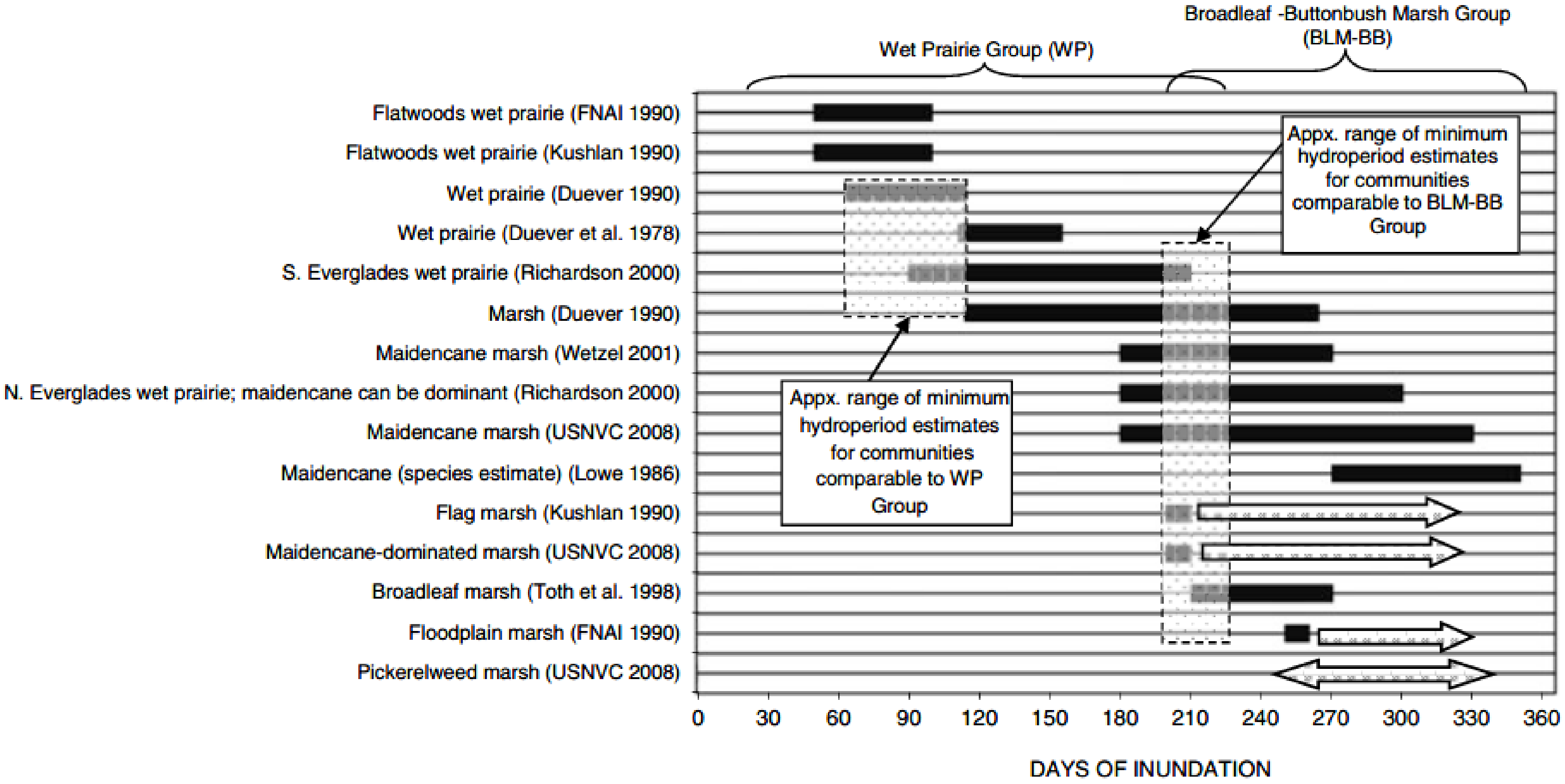


Figure 9-14. Published estimates of hydroperiod durations for Florida marsh plant communities comparable to Wet Prairie (WP), *Panicum hemitomon* (maidencane, PhWP), and Broadleaf Marsh-Buttonbush (BLM-BB) groups that predominated in the pre-channelization floodplain (Figure 3 from Spencer and Bousquin 2014; reproduced with permission). Nomenclature follows that of cited sources. Grayscale bars with arrowheads indicate estimates for which only a minimum inundation duration was described, or, in the case of Pickerelweed Marsh, a numerical estimate was not provided (inundation was described as "most of year").

Kushlan (1990) described the hydrologic requirements of BLM communities, including wet season water depths between 1 and 3.3 ft, periods of inundation longer than 200 days per year, and a seasonal drying period. During the KRRP Demonstration Project, BLM reestablished from remnant BLM communities after 7 to 9 months (210 to 270 days) of inundation (Toth et al. 1998). Based on the review by Spencer and Bousquin (2014), the minimum hydrologic requirements for BLM hydroperiod are estimated as a minimum of 1 ft of depth for > 210 days. The depth estimate of 1 ft is the lower end of the range given by Kushlan (1990); the flood duration of 210 days is the lower end of the range reported by Toth et al. (1998) for BLM in the Kissimmee River floodplain and is approximately the midpoint of the range of minimum hydroperiod estimates for BLM as estimated by Spencer and Bousquin (2014) (**Figure 9-14**). Pre-regulation stage data for the Kissimmee River were analyzed to verify these conditions occurred in the pre-regulation system and to determine the reference seasonality of inundation and the frequency of years in which they occurred.

A recession event is defined as a period when water depth is decreasing on the floodplain. A recession event can be characterized by its recession rate (rate of water depth decrease) or duration; both characteristics have important implications for patterns of inundation and are standard metrics used in other studies (Poff et al. 1997, Rood et al. 2005). Recession rates and the durations of events are related to hydroperiod, with faster rates of recession or shorter durations of events resulting in shorter hydroperiods. The characteristics of recession events affect how and when organisms can use the floodplain, the ability of organisms to access the floodplain from the river channel, and the exchange of organic and inorganic materials between the floodplain and river channel. Recession events in the pre-channelization Kissimmee River typically were very slow (< 1 ft per 30 days) and of long duration (**Figure 9-20** later in this chapter) (USACE 1991, Anderson 2014). In the Kissimmee River, recession rate is a result of the rate of reduction in inflow discharge. Conversely, an increase in inflow during a recession event will cause an increase in water depth, called a stage reversal. Reversals can be disruptive of fish and wildlife foraging and reproductive activities in the floodplain (e.g., Frederick and Collopy 1989, Smith et al. 1995).

In summary, the pre-channelized system was characterized by much longer flood events, much slower recession rates, and fewer reversals than occurred in the Baseline and Interim periods.

Methods

Sources of stage data used to calculate the hydroperiod and recession rate metrics are summarized in **Table 9-4**. Reference Period stage data are from continuous stage recorders operated by the USGS (Parker et al. 1955). Data for the Baseline and Interim periods are from continuous SFWMD stage recorders. Mean daily stage was converted to water depth by subtracting the floodplain ground elevation at each station; negative (belowground) depths were converted to 0 ft. Measurements for calculations of depth were from locations where BLM occurred in the pre-channelization Reference Period, termed here BLM depth. For the Reference Period, BLM depth was calculated by comparing stage measurements at stations located in the river channel with an average ground elevation for the floodplain immediately adjacent to the stage recorders (Obeysekera and Loftin 1990). These stations were located upstream or downstream of, but not in, the Phase I area. Water depth fluctuates in parallel at these sites, however (**Figure 9-15**), which indicates depth dynamics during the Reference Period were comparable to those in the Phase I area during the same time period. Thus, depth measurements at these sites are appropriate for developing restoration performance measures and were used to develop Expectations 3 (hydroperiod) and 4 (recession events) (Anderson and Chamberlain 2005).

For the Baseline Period, water surface elevation was calculated as the average of the tailwater stage at S-65B in the C-38 canal (near the upper end of the Phase I area) and the headwater stage at S-65C (near the lower end of the Phase I area). Water level in the C-38 canal between the two stations was essentially flat during the Baseline Period. BLM depth was calculated by comparing the mean water elevation in the canal with the ground elevations at the five BLM stations in the Phase I area.

For the Interim Period, water depth in the Phase I area was evaluated at five stations at which BLM occurred in the pre-channelization vegetation map in the northern floodplain of the Phase I area (and which are unaffected by the backwater from S-65C). Ground elevation was calculated for each station by averaging the elevations from a surveyed digital elevation model within a 100-ft radius circle centered on the stage recorder. Depth was determined for the Interim Period using water surface elevations measured at each stage recorder minus its ground elevation. Hydroperiod was calculated by counting the number of consecutive days that BLM depth was at least 1 ft. Periods of time when BLM depth declined below 1 ft for no longer than 14 days, but stayed above 0.5 ft in BLM depth, were regarded as not resulting in a significant gap in the event's duration; these days therefore were included in counts of days for a single hydroperiod event.

A recession event is defined as beginning with a decline in water depth and ending when depth decreases to 0 ft, levels out, or the decline is interrupted by an increase in depth (a depth reversal) of at least 1.5 ft. A new recession event begins when depth begins to decrease following a depth reversal of at least 1.5 ft. The mean recession rate for an event was calculated by averaging the daily decrease in depth during the event. For convenience, the recession rate was multiplied by 30 days to provide a recession rate per 30 days. For purposes of counting the number of recession events in a water year, only those events that began in a water year were considered part of that year.

Table 9-4. Sources of stage used to calculate depth in the Reference, Baseline, and Interim periods.

Period	Station	Location	Period of Record (Water Years)	Floodplain Ground Elevation (ft NGVD29)
Reference	Fort Kissimmee	Upstream of Phase I	WY1943–WY1962	43
Reference	Fort Basinger	Downstream of Phase I	WY1933–WY1959	28.5
Reference	Lower Kissimmee River	Downstream of Phase I	WY1931– WY1962	21
Baseline	S-65B tailwater	Upstream of Phase I	WY1972–WY1999	[a]
Baseline	S-65C headwater	Downstream of Phase I	WY1972–WY1999	[a]
Interim	PC55	Phase I area	WY2002–WY2018	37.36
Interim	PC53	Phase I area	WY2002–WY2018	37.40
Interim	PC52	Phase I area	WY2002–WY2018	37.56
Interim	PC44	Phase I area	WY2002–WY2018	35.93
Interim	PC42	Phase I area	WY2002–WY2017	36.00

a. Baseline Period stage data were compared to ground elevations at the five stations in the Interim Period.

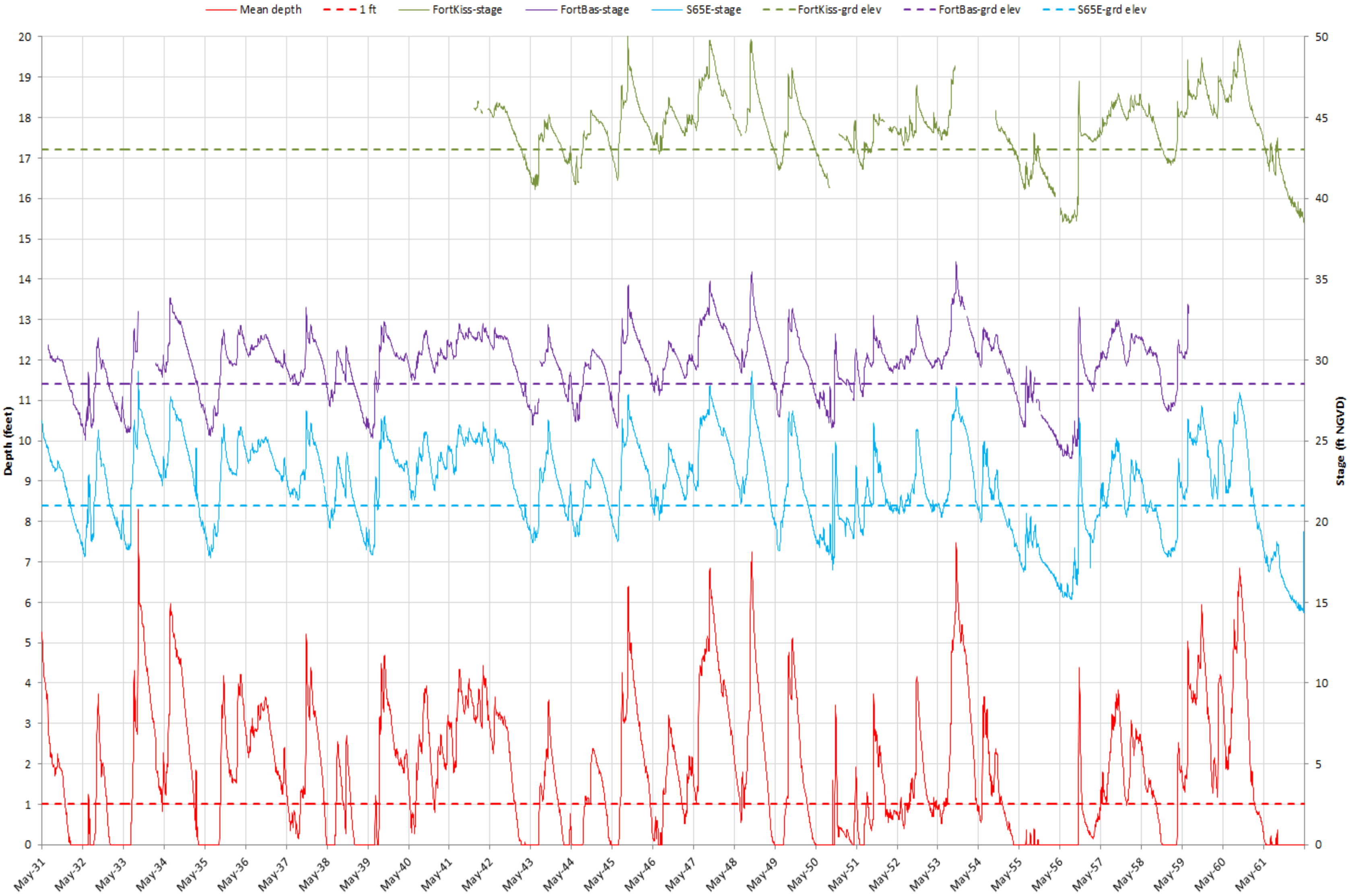


Figure 9-15. Stage at three sites relative to Kissimmee River floodplain ground elevations (dashed lines) and the resulting BLM depth averaged for three sites relative to a 1 ft reference line during the Reference Period.

Results

Expectation 3 (Hydroperiod)

> *Stage hydrographs that result in floodplain inundation frequencies comparable to pre-channelization hydroperiods, including seasonal and long-term variability characteristics.*
>
> > *Component A: Fifty-nine percent of water years will have a mean depth at BLM sites ≥ 1 ft for 210 consecutive days.*
> >
> > *Component B: Forty percent of water years will have a mean depth at BLM sites ≥ 1 ft for 210 consecutive days in the August–February window.*

Hydroperiods during the Reference Period. During the pre-regulation Reference Period, BLM depth was ≥ 1 ft for at least 210 consecutive days in 19 of 32 water years, or 59% of water years. This provides a metric and target (59% of water years) for Component A, evaluation of hydroperiod durations. During the Reference Period, BLM depth exceeded 1 ft almost every year for extended periods of time with a minimum of 120 consecutive days (**Figure 9-16**). Six water years within the Reference Period had 1 ft or more of depth continuously throughout all months (**Figure 9-16**). Several continuous hydroperiod events with BLM depth of at least 1 ft began in one water year and continued into the next; two began in one year and continued through a second water year into a third water year (**Figure 9-16**). In only two water years did BLM depth not exceed 1 ft, WY1956 and WY1962 (**Figure 9-16**); both years were classified as severe droughts in the Kissimmee Basin using the Palmer Drought Severity Index (Abtew et al. 2002).

The continuous periods of inundation at depths of at least 1 ft exhibited distinct seasonality (**Figure 9-16**) in the Reference Period. This is seen most clearly by plotting the median frequency of BLM depth ≥ 1 ft for each month of the Reference Period (**Figure 9-17**). The analysis indicates BLM depth was 1 ft or more for a 7-month (212-day) window from August through February in at least 50% of water years, providing a dominant window of occurrence for evaluating Component A of Expectation 3. BLM depth was ≥ 1 ft for 210 days consecutively in the August–February window in 11 water years. Two additional years had more than 210 days but were short by less than 10 days of 210 days in the August–February window. Given the narrowness of the difference, it is reasonable to include these two additional years, which gives a total of 13 of 32 water years, or 40% of water years. This provides a second metric and target for Component B of the hydroperiod expectation.

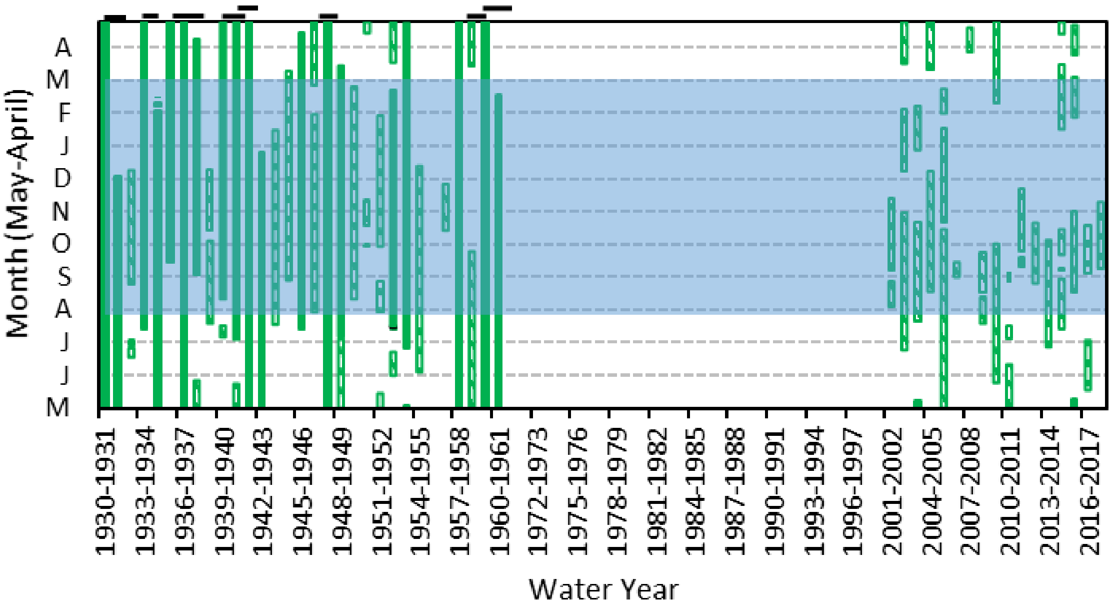


Figure 9-16. Periods and timing of Kissimmee River floodplain events with BLM depth ≥1 ft during the Reference Period (WY1931–WY1962), Baseline Period (WY1972–WY1999), and Interim Period (WY2002–WY2018). Continuous events are indicated by green bars; solid bars identify events that were at least 210 days long in a water year. Black bars at the top of the graph link years where an event began in one water year and continued into the next. Events were identified using a 14-day 0.5-ft buffer as described in the text. The shaded rectangle indicates the target window of August through February. The horizontal axis does not include WY1963–WY1971 or WY2000–WY2001, which were periods of construction for the C&SF Project and Phase I of KRRP, respectively. During the Reference Period, 59% of water years had BLM depth of at least 1 ft for at least 210 consecutive days. The Baseline Period never had BLM depth of 1 ft or more. During the Interim Period to date, BLM depth of at least 1 ft has occurred intermittently for relatively short intervals of time, and intervals of BLM depth of at least 1 ft were separated by long gaps, often a month or more.

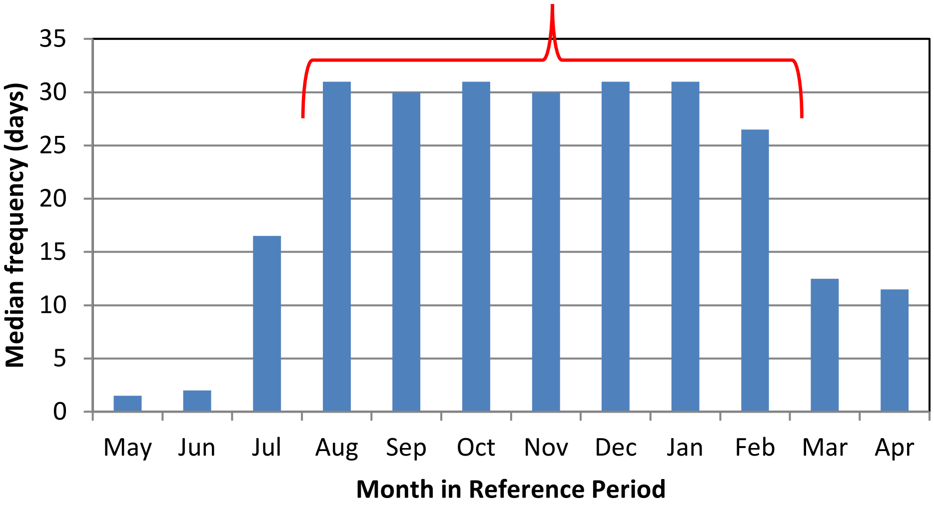


Figure 9-17. Median frequency of days in the pre-regulation Reference Period for the Kissimmee River floodplain that mean water depth was ≥ 1 ft in each month of the water year. Median values were calculated for 32 years (WY1931–WY1962). The red bracket encloses the dominant target window of August through February.

Hydroperiod Evaluation (Expectation 3) in the Baseline Period. During the Baseline Period prior to backfilling of the C-38 canal, water levels in Pool C did not exceed ground elevations at any of the five BLM sites in the Phase I area (**Figure 9-18**) due to the canal's presence. Consequently, there were no events when BLM depth was ≥1 ft; therefore, the 210-consecutive day criterion hydroperiod duration was not met in any water year (Component A) or in the August–February window (Component B) of the Baseline Period.

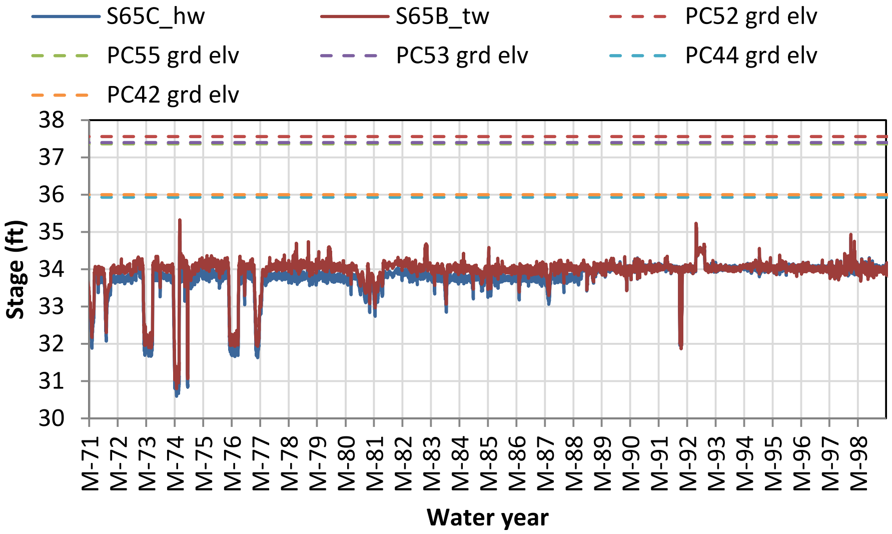


Figure 9-18. Baseline Period water surface elevation in the C-38 canal in relation to ground elevation at the Phase I area stage recorders used to calculate BLM depth for the Kissimmee River floodplain.

Hydroperiod Evaluation (Expectation 3) in WY2018 and the Interim Period. WY2018 had one event with BLM depth of at least 1 ft (**Figure 9-16**); it corresponded to the second of the two inundation events characterized by discharge greater than 1,400 cfs (described in the *Kissimmee Basin Hydrologic Conditions and Water Management in Water Year 2018* section earlier in this chapter). The event lasted 63 days (September 10–November 11), far shorter than the desired duration of 210 days (**Figure 9-19**). The WY2018 event did not met the criterion of BLM depth of at least 1 ft for 210 days for the water year (Component A) or the August–February window (Component B).

In the Interim Period to date, every year, including drought years, had one or more events in which BLM depth exceeded 1 ft (**Figure 9-16**); however, the longest event in the Interim Period was only 169 consecutive days, and in the majority (14 of 17) of Interim Period water years, the longest events were less than 120 days (**Figure 9-19**). Therefore, none of the events in the Interim Period have met the 210-day criterion (Component A) or the criterion for the more restrictive August–February window (Component B). Only one year in the Interim Period (WY2006, in which Hurricane Wilma passed over the basin at the end of wet season), came close to meeting the criterion for that water year (Component A) or the seasonal window (Component B). However, for WY2006 to have met the 210-consecutive day criterion for Component A, the two longest periods of continuous BLM depth of at least 1 ft would have had to have been connected by disregarding a gap of 21 days (**Figure 9-16**). To have met the criterion during the August–February window (Component B), a second gap of 28 days also would have had to have been disregarded.

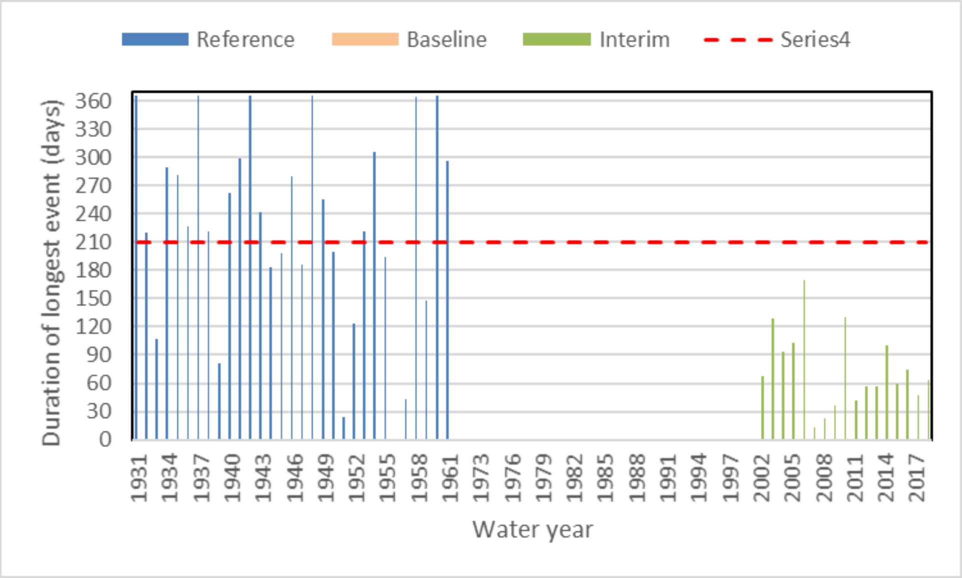


Figure 9-19. Kissimmee River floodplain duration of the longest event with BLM depth of least 1 ft in a water year during the Reference Period (WY1931–WY1962), Baseline Period (WY1972–WY1999), and Interim Period (WY2002–WY2018). The horizontal axis does not include WY1963–WY1971 or WY2000–WY2001, which were periods of construction for the C&SF Project and Phase I of KRRP, respectively. No events occurred in the Baseline Period.

Expectation 4 (Recession Events)

> *Stage hydrographs that result in floodplain recession events with rates of water level decrease, duration, and timing that are comparable to pre-channelization events, including seasonal and long-term variability characteristics.*
>
> > *Component A: Seventy-two percent of recession events will have a mean recession rate < 1 ft per 30 days.*
> >
> > *Component B: One hundred percent of recession events will have a mean recession rate < 2 ft per 30 days.*

Recession Events in the Reference Period. The Reference Period included 43 recession events, or a frequency of 1.3 events per water year (**Figure 9-20**). Only four Reference Period years had no events, although two of these (WY1932 and WY1943) had substantial portions of recession events that began in the previous water year. A single recession event occurred in 15 water years (47%), two events in 11 water years (34%), and three events in only 2 water years (6%). Recession rates ranged from 0.33 to 1.86 ft per 30 days and averaged 0.85 ft (± 0.2 SE) per 30 days over all events (**Figure 9-20**). Recession events in the Reference Period averaged 146 days (± 17 SE) in length. Recession rates < 1 ft per 30 days occurred in 31 of 43 recession events, or 72% of events, which provides a target for Component A. During the Reference Period, 100% of recession events had a mean recession rate < 2 ft per 30 days, which provides an upper limit on recession rates and the target for Component B.

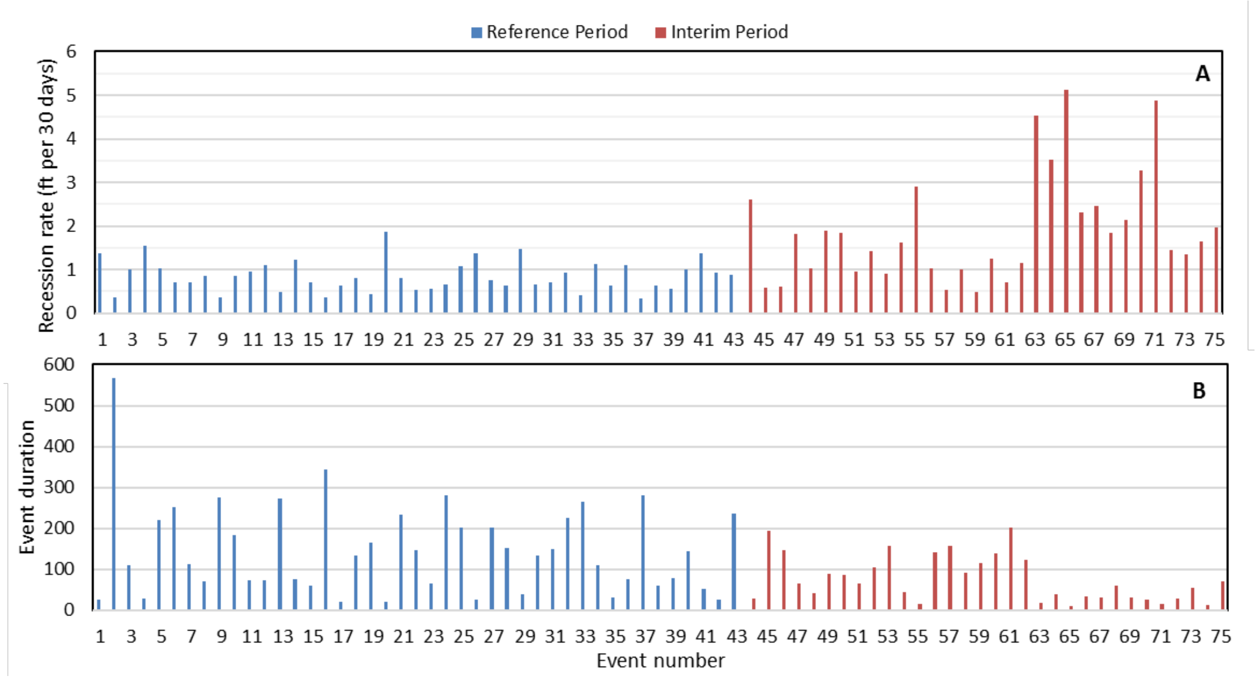


Figure 9-20. (A) Recession rates and (B) event duration for recession events during the Reference Period (WY1931–WY1962, blue bars) and the Interim Period (WY2002–WY2018, red bars) in the Kissimmee River floodplain. The Baseline Period (WY1972–WY1999) is not shown because no recession events occurred.

Recession Events (Expectation 4) in the Baseline and Interim Periods. Water levels in the C-38 canal fluctuated very little during the Baseline Period and never exceeded ground elevations at the sites used for calculating BLM depth in the Phase I area (**Figure 9-18**). Consequently, there were no recession events during the Baseline Period.

WY2018 had two recession events that corresponded to the two inundation events described in the *Kissimmee Basin Hydrologic Conditions and Water Management in Water Year 2018* section earlier in this chapter. The addition of these two recession events (events 74 and 75 in **Figure 9-20**) brought the Interim Period total to 32 recession events, or 1.9 events per water year (**Figure 9-20**). During the Interim Period, mean recession rates for recession events ranged from 0.49 to 5.13 ft per 30 days, with a mean rate over all events of 1.90 ft (± 0.22 SE) per 30 days (**Figure 9-20**). The duration of recession events ranged from 10 to 203 days and averaged 76 days (± 10 SE). Only 8 events (25% of events) had recession rates < 1 ft per 30 days; 22 events (69%) had rates < 2 ft per 30 days. The two WY2018 recession events had mean recession rates of 1.65 ft per 30 days and 1.97 ft per 30 days (**Figure 9-20**). None of the WY2018 events had a rate < 1 ft per 30 days, and both had a rate < 2 ft per 30 days.

Overall, the Interim Period had enough water level fluctuation and floodplain inundation to have had some recession events; therefore, the Interim Period was an improvement over the Baseline Period, which had no recession events. However, in the Interim Period, recessions have tended to be faster than those in the Reference Period. As a result, Interim Period values to date for the two recession rate metrics did not meet the expectation targets based on the Reference Period data (**Figure 9-21**). Nearly a third of Interim Period recession events were faster than any that occurred in the Reference Period.

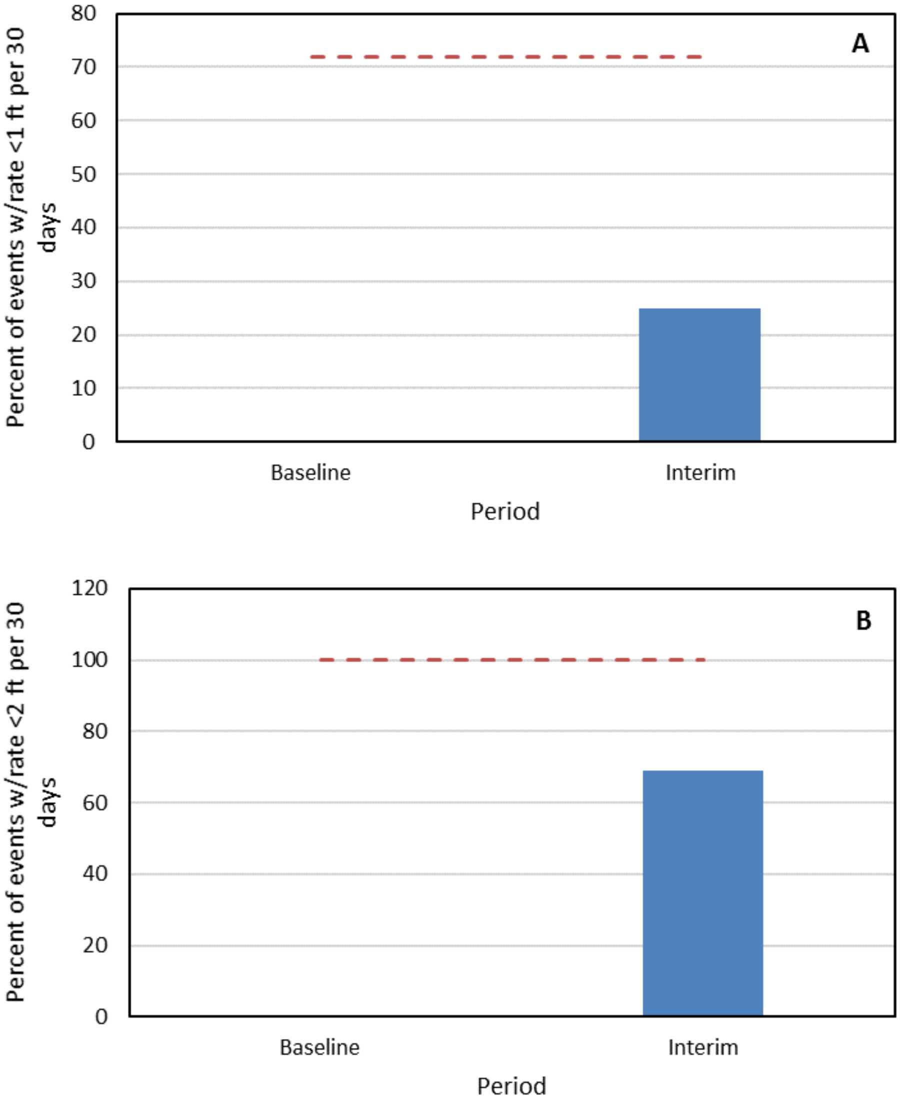


Figure 9-21. Comparison of the percent of Kissimmee River floodplain recession events that had rates < 1 ft per 30 days (Component A) and < 2 ft per 30 days (Component B) during the Baseline Period (WY1972–WY1999) and Interim Period (WY2002–WY2018). Dashed red lines are the target percentages based on the frequency of events during the pre-channelization Reference Period (WY1932–WY1962). Frequent reductions to low discharge result in disjunct floodplain inundation events separated by periods of floodplain drying.

To summarize, comparisons among the Reference, Baseline, and Interim periods indicate recessions in the natural (Reference) system were prolonged, in sharp contrast to the complete absence of recessions in the Baseline Period and the multiple, shorter recessions in the Interim Period. In recent years (events 63 to 75 in WY2015–WY2018) of the Interim Period, recession events have tended to be shorter and faster than earlier years of the Interim Period (**Figure 9-20**) due to a combination of factors, especially operations to keep the Headwaters Lakes stages high, above-average rainfall, and frequent schedule exceedances in the Headwaters Lakes due to operations to hold lake stage in close proximity to the regulation lines, resulting in rapid discharge increases for flood control followed by decreases to maintain high lake stages upstream.

Excessively fast floodplain recession rates have important implications for restoration success. A slow recession rate was an important characteristic of floodplain inundation events during the Reference Period and interacted with other aspects of the hydrologic regime to produce the long hydroperiods or flood pulses typical of the unregulated ecosystem (i.e., slow floodplain recession rates were a consequence of the characteristic gradual decline in flow from the headwaters lakes). Faster recession rates, as seen in the Interim Period and especially in recent years, are largely due to operations that impose unnatural demands on the system. These operations disrupt the continuity and duration of flood pulses, with the consequence of pronounced intervals of dry conditions that are unsuitable for the floodplain's signature marshes (Spencer and Bousquin 2014). If continued, such operations will inhibit recovery of the Kissimmee River and floodplain. Also characteristic of the Interim Period (**Figure 9-20**) are extreme changes in Kissimmee River floodplain stage (stage reversals) due to rapid increases in discharge at S-65/S-65A to raise or maintain upstream lake stages, which have been identified as a problem for restoration of the Kissimmee River (Cheek et al. 2014). Floodplain reversals as small as 0.3 ft (much smaller than the 1.5-ft reversal used here to identify new recession events) have been associated with abandonment of nests by wading birds (Frederick and Collopy 1989, Smith et al. 1995).

Relationship of Expectations 3 (Hydroperiod) and 4 (Recession Events) to Discharge. BLM depth is influenced, to a small extent, by direct rainfall and associated LKB runoff, but it almost completely depends on inflow discharge through S-65 via S-65A (Anderson 2014). Thus, the way these structures are operated directly influences floodplain inundation characteristics in the Phase I area as evaluated by Expectations 3 and 4, and therefore the extent to which the hydrologic criteria can be met. Thus, recovery of the biota that depend on improvement in and eventual reestablishment of pre-regulation hydrology for recovery is strongly influenced by water management operations.

S-65 operations were recommended to be modified using discharge plans for the first time in the 2015 wet season and again in the 2017 wet season to address these expectations to improve hydrologic performance for KRRP, as required by USACE (1991, 1996). Water operations during the 2017 wet season involved a recommendation to implement the HRS-1400-50.0 discharge plan as described in the *Kissimmee Basin Hydrologic Conditions and Water Management in Water Year 2018* section earlier in this chapter. Although the plan is intended to improve hydrologic performance for Expectations 3 (hydroperiod) and 4 (recession events), it is not expected to fully meet the criteria for either expectation. How well the plan improves hydrologic performance in any given year until the HRS is implemented will be influenced by the quantity and timing of rainfall. However, implementation of 1,400-cfs discharge plans during the 2015 and 2017 wet seasons resulted in promising improvements in the performance of Expectations 3 and 4 that could have been enhanced by continuing to follow the plan into the dry season. Implementation of the plan during the 2015 and 2017 wet seasons resulted in a single floodplain inundation and recession event during each wet season, with BLM hydroperiods of 76 days and 63 days, respectively. Holding discharge at 1,400 cfs during these events extended the period of time BLM depth was at least 1 ft, although the resulting durations were well short of the target duration of 210 days, partly due to rainfall. This underscores the importance of plan implementation across all years to capitalize on years of sufficient rainfall to provide prolonged floodplain inundation and periods of higher stage in the Headwaters Lakes using balanced discharge plans. Even so, this outcome suggests a promising direction for Kissimmee Basin operations when balancing stage in the Headwaters Lakes against S-65 discharge to achieve benefits in both systems without harming either. Holding discharge at 1,400 cfs during the discharge rampdown also improved hydrologic performance for Expectation 4 by increasing the duration of the recession event and slowing the recession rate. No negative effects on the lakes have been noted except slightly lower stages over the period of implementation.

The SFWMD will continue to evaluate, refine and implement 1,400-cfs discharge plans in future years. Modeling suggests that consideration should be given to extending a modified version of a discharge plan throughout the year as well as potentially lowering the threshold stage to 49.5 ft to improve performance. The plans are examples of hydrologically and ecologically balanced operations designed to link discharge for the KRRP to rainfall via upstream lake stage to achieve mutually beneficial operations for these two inextricably connected parts of the Kissimmee Basin ecosystem. The plan does not attempt to fully meet the KRRP expectations for hydroperiod and recession events during the Interim Period, although implementations of the 1,400-cfs discharge plan have demonstrated that substantial improvements in performance for the hydrologic expectations can be made without the additional storage that will be provided by the HRS. In many circumstances, implementation of plans of this kind will require that discharge not be reduced to low levels to reach short-term goals such as forcing slightly higher or maintaining stable stages in the Headwaters Lakes. In some years, this will mean lower average lake stages than would occur without use of a stage-discharge relationship, but for the lakes, the resulting relationship of variation in lake stage with discharge would be more similar to what happened in the pre-channelization system (see Figure 9-10 in the *Kissimmee Basin Hydrologic Conditions and Water Management in Water Year 2015* section in Chapter 9 of the 2016 SFER – Volume I) and better approximates both the natural relationship of lake stage to flow and the natural variability in stage that is characteristic of healthy lakes (National Research Council 1992). Extension of the plan throughout the dry season would help address another issue identified in previous years—that rapid changes in discharge to keep the Headwaters Lakes stage near the regulation schedule or to follow a stage recession line in the lakes can result in harmful depth fluctuations in the Kissimmee River floodplain. Current operational guidelines allow maximum rates of discharge decrease and increase that are much faster than occurred in the Reference Period but that are designed to address realistic operational needs. Operations to maintain high stages near the regulation line in the Headwaters Lakes (and to a lesser extent in East Lake Tohopekaliga and Lake Tohopekaliga), or to precisely follow dry season stage recession lines in these lakes, create conditions under which all or most inflow from rainfall events must be quickly discharged to the river, rather than balancing reversals resulting from rainfall between the lakes and the river. The resulting abrupt reductions and increases in depth on the Kissimmee River floodplain are harmful to the river, inhibiting improvements in performance of the KRRP hydrologic goals.

Summary

The performance of hydrologic Expectations 3 (hydroperiod) and 4 (recession events) in WY2018 was influenced by the implementation of the HRS-1400-50.0 during the 2017 wet season and the above-average wet season rainfall, especially in association with Hurricane Irma.

Expectation 3:

- The targets for Expectation 3 (hydroperiod) were not met in WY2018 or in any year of the Interim Period thus far (WY2002–WY2018).
- Performance for Expectation 3 (hydroperiod) can be improved by implementing operations designed to increase the number of consecutive days that inflow discharge of 1,400 cfs or greater is maintained.

Expectation 4:

- The targets for Expectation 4 (recession events) were not met in WY2018 or in any year of the Interim Period thus far (WY2002–WY2018).
- Performance for Expectation 4 (recession events) can be improved by slowing the rate of recession, especially by eliminating the practice of decreasing discharge to low levels to hold the Headwaters Lakes stable at high stages for extended periods.

Use of discharge plans such as the one implemented in WY2018 can improve hydrologic conditions for Expectations 3 (hydroperiod) and 4 (recession events).

DISSOLVED OXYGEN

Dissolved oxygen (DO) directly affects aquatic life through oxygen (O_2) availability and the metabolism of aquatic ecosystems (Colangelo 2007, Hauer and Lamberti 2007). DO concentration can influence the growth, distribution, and structural organization of aquatic communities, thereby impacting the productivity of aquatic ecosystems (Wetzel 2001). For these reasons, DO was chosen as one of the metrics used in KRREP expectations for evaluation of the status and success of the KRRP (Colangelo and Jones 2005).

DO in the Kissimmee River is a function of the balance between primary production, reaeration, and respiration, which are influenced by many factors, including temperature, water depth, stage, and discharge at water control structures S-65A and the former S-65C (Chen et al. 2016). Thus, operation of these structures has important implications for reduction of the severity and/or duration of hypoxic and anoxic events in partially restored sections of the Kissimmee River.

Expectation 8

> *Mean daytime concentration of DO in the Kissimmee River channel at 0.5 to 1.0 m depth will increase [a] from < 1–2 mg/L to 3–6 mg/L during the wet season (June–October) and [b] from 2–4 mg/L to 5– 7 mg/L during the dry season (November–May). [c] Mean daytime DO concentrations within 1 m of the channel bottom will exceed 1 mg/L more than 50% of the time. [d] Mean daily (24-hour) DO concentrations will be > 2 mg/L more than 90% of the time (updated from Colangelo and Jones 2005).*

Reference (Pre-channelized Period) and Baseline (Channelized Period) Data

Based on reference and baseline data, restoration of the Kissimmee River is expected to improve DO concentrations in the river primarily by reintroducing flow to the channel, which is expected to reduce the amount of organic matter on beds of non-flowing (remnant) channels after construction of the C-38 canal (Colangelo and Jones 2005). DO data from the Kissimmee River were not available prior to channelization. For this reason, available daytime DO data from nearby free-flowing blackwater streams where DO had been measured frequently from 1973 to 1999 were used to estimate reference (pre-channelization) conditions for the Kissimmee River (**Table 9-5**). For some of these streams, more than 10 years of data were available (Colangelo and Jones 2005). Baseline (channelized period) DO data were obtained from monitoring stations in non-flowing remnant river runs of the Kissimmee River and the C-38 canal prior to Phase I construction. For these data, grab samples were collected monthly within a time window between 10 am and 2 pm from WY1996 to WY1999. Expectation 8 components [a], [b], and [d] were developed based on these reference and baseline data. Component [c] was developed based on weekly DO depth profiles sampled in Micco Bluff Run and Montsdeoca Run in the Phase I project area of the Kissimmee River from May to October 1999. Details and summaries of reference and baseline data and expectation development are available in Colangelo and Jones (2005).

Interim (Post-Phase I Construction) Data

DO monitoring has continued in the Phase I Interim Period (post-Phase I construction) at some of the stations that were used to establish reference and baseline DO conditions. The same or similar grab sampling methods have been used to provide data for evaluating changes in DO before and after restoration construction (**Table 9-5**). Grab samples used for evaluation of Components [a] and [b] were collected monthly from sampling stations KREA91, KREA92, and KREA97 in Pool A and KREA93, KREA94, and KREA98 in the Phase I area between 10 am and 2 pm. Daytime DO concentrations within 1 m of the channel bottom were measured at stations KREA94 and KREA98 in the Phase I area for evaluation of Component [c]. Daytime-only measurements were used for compatibility with the available reference data as described earlier and in Colangelo and Jones (2005).

Table 9-5. Reference, baseline, and post-construction DO sampling for performance evaluation in the Kissimmee River Restoration Project.

Period	Sampling Type and Frequency	Depth	Dates Collected	Location	Purpose
Reference (represents pre-channelized condition)	Grab, daytime; Monthly	0.5–1.0 m	1973–1999	Reference nearby free-flowing blackwater streams	Expectation and target development
Baseline	Grab, daytime; Monthly	0.5–1.0 m	1996–1999	Non-flowing remnant runs in the Kissimmee River	Establish baseline for comparison with restored condition
Post-Phase I Construction – Interim and Final	Sonde; Continuous	0.5–1.0 m	2002–present	Kissimmee River Phase I area	Expectation evaluation; Hypoxia/anoxia investigations
Post Phase I Construction – Interim and Final	Grab, daytime; Monthly	0.5–1.0 m and within 1m of channel bottom	2002–present	Remnant runs in the Kissimmee River	Expectation evaluation

For evaluation of Component [d] during the Interim Period, continuous monitoring of daily (24-hour) DO at stations PC33 and PC62 was conducted using stationary DO sondes 0.5 to 1 m from the water surface in the Phase I river channel (**Table 9-5**). The data were collected continuously at 15-minute intervals, day and night. Data from these stations also are used to provide technical guidance for adaptive management of discharge at water control structures S-65 and S-65A.

For statistical evaluations of a restoration effect on DO, the difference (ICd) between the Impact (Pool BC of the Phase I area where flow was reestablished in 2001) and Control (Pool A, which was not altered by restoration construction) area means was calculated for daytime DO collected monthly at the KREA stations using a BACIPS sampling design (Bousquin and Colee 2014, Osenberg et al. 2006). The ICd data were tested for autocorrelation using a Durbin-Watson test, which indicated no significant autocorrelation. A t-test was used to test the difference between the ICd means for daytime DO in the Before (Baseline) and After (Interim) periods (Stewart-Oaten et al. 1992). Statistical significance was evaluated at $\alpha = 0.05$.

Post-Construction DO through WY2018

Since completion of Phase I construction (WY2002-WY2018), DO in the Phase I Impact area (Pool BC) has averaged 2.83 ± 0.11 mg/L (1 SE) during the wet season and 6.52 ± 0.09 mg/L during the dry season (**Figure 9-22**). By comparison, post-construction DO in the Control area (Pool A) was significantly lower at 1.70 ± 0.12 and 3.39 ± 0.10 mg/L during the wet and dry seasons, respectively ($p < 0.01$). Mean annual daytime DO has been significantly higher in the Phase I area, 4.97 ± 0.18 mg/L than in Pool A, 2.67 ± 0.13 mg/L for the 17 water years following completion of Phase I construction ($p < 0.01$) (**Figure 9-23**).

A t-test on the ICd means of baseline and post-Phase I construction samples indicated that DO greatly improved in the Phase I Impact area during post-Phase I period compared to the Control area. The ICd for DO was significantly higher for the post-construction period (2.28 ± 0.18 mg/L) than for the baseline period (-0.18 ± 0.19 mg/L) ($p < 0.01$).

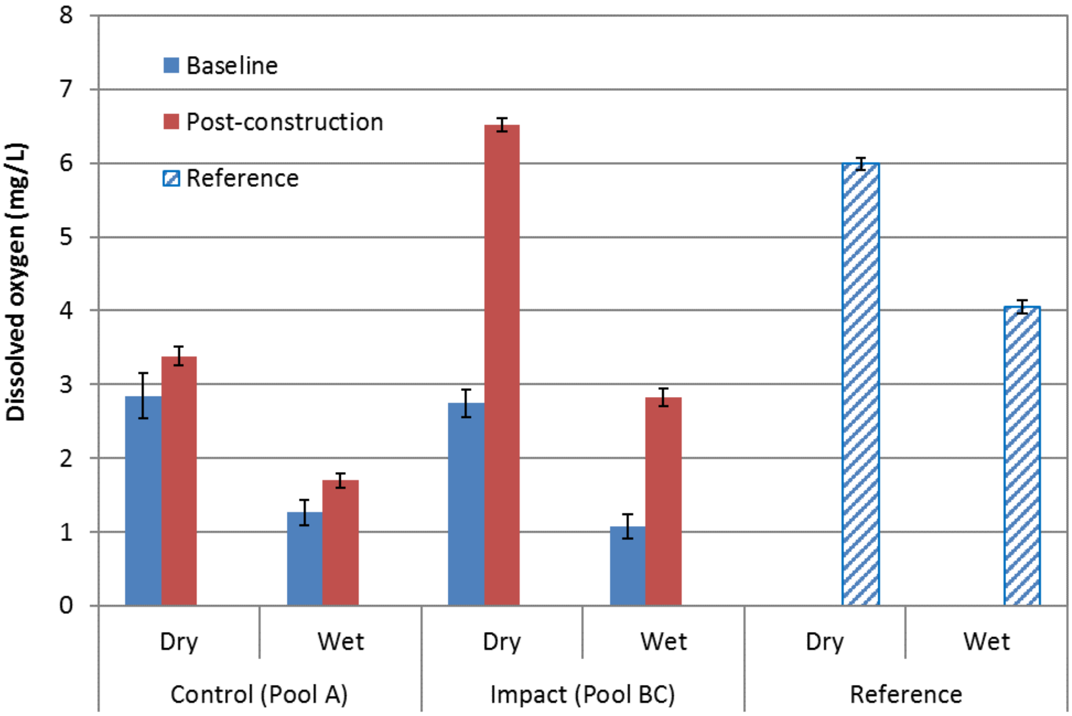


Figure 9-22. Daytime DO concentrations (mean ± SE) in reference streams (period of record = WY1973–WY1999) and Control and Impact areas in wet and dry seasons during the baseline (WY1997–WY1999) and post-Phase I construction (WY2002–WY2018) periods. Impact areas in Pool BC have had reestablished flow since Phase I construction was completed in 2001; Control areas in Pool A have not been altered by KRRP construction activities and therefore remain non-flowing.

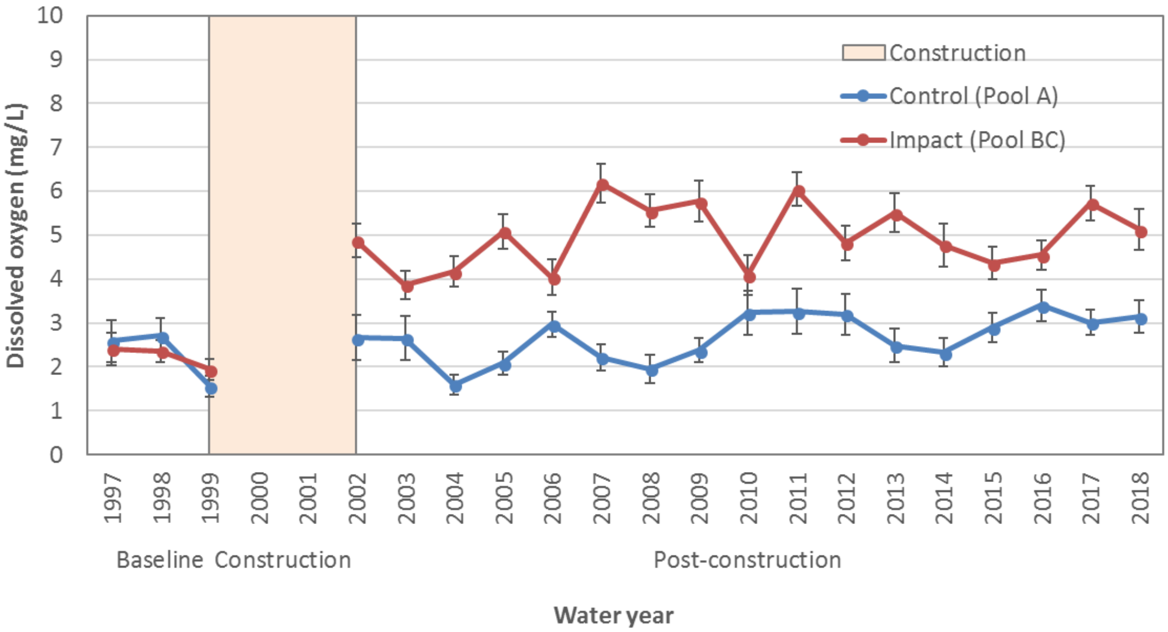


Figure 9-23. Daytime DO concentrations (mean ± SE) of sampling stations KREA91, KREA92, and KREA97 in Pool A and sampling stations KREA93, KREA94, and KREA98 in the Phase I Impact area (Pool BC) of the Kissimmee River for each water year during the baseline (WY1997–WY1999) and post-Phase I construction periods (WY2002–WY2018).

In WY2018, two of the four expectation metrics, Components [b] and [c], were met (**Table 9-6**). Mean daytime DO concentration in the wet season in the Phase I area decreased from 3.40 mg/L in WY2017 to 2.43 mg/L in WY2018 ($p < 0.01$), not meeting component [a] of 3–6 mg/L. However, for Component [d], mean daily DO concentrations were > 2 mg/L in the river channel in WY2018 78% of the time, and therefore did not meet the Component [d] target of > 90% of the time annually. This outcome reflects two hypoxic/anoxic events occurring in the wet season of WY2018 that lasted 54 days (see *Hypoxic and Anoxic Events, S-65A Discharge and Local Rainfall* subsection below).

Table 9-6. Restoration expectation component metrics and WY2018 values for dissolved oxygen.

Expectation Components	WY2018 Value	Metric Achieved in WY2018	Data Source
[a]. Mean daytime DO concentration in the river channel at 0.5–1.0 m depth will increase from < 2 mg/L to 3–6 mg/L during the wet season (June–October).	2.43 ± 0.42 mg/L	No	KREA93, KREA94, and KREA98 (grabs)
[b]. Mean daytime DO concentration in the river channel at 0.5–1.0 m depth will increase from 2 to 4 mg/L to 5–7 mg/L during the dry season (November–May).	7.06 ± 0.30 mg/L	Yes	KREA93, KREA94, and KREA98 (grabs)
[c]. DO concentrations within 1 m of the channel bottom will be > 1 mg/L for more than 50% of the time annually.	83%	Yes	KREA94 and KREA98 (grabs)
[d]. Mean daily DO concentrations in the river channel will be > 2 mg/L for more than 90% of the time annually.	78%	No	Sondes at PC33 and PC62 (continuous)

As in previous years, monthly daytime and daily mean DO concentrations in WY2018 showed a seasonal pattern, with high DO levels in the dry season and lower DO in the wet season (**Figures 9-24** and **9-25**), that was not seen prior to reestablishment of flow (Chen et al. 2016). Reestablishment of flow likely reduced sediment oxygen demand by eliminating the organic layer that had accumulated under non-flowing, channelized conditions during the Baseline Period (Anderson 2014); reaeration by flowing water may have been a factor also.

DO Sag Events, S-65A Discharge and Local Rainfall

Post-Phase I DO in the Kissimmee River is dynamic, exhibiting substantial temporal variability (**Figures 9-24** and **9-25**). DO concentration is lower in the wet season, averaging 2.83 mg/L, than in the dry season, which averaged 6.52 mg/L over WY2002 to WY2018, in part because the rates of aquatic gross primary productivity and respiration in the river are higher during the wet season, averaging 5 and 14 grams of O_2 per square meter per day (g $O_2/m^2/d$), respectively, than in the dry season, averaging 3 and 5 g $O_2/m^2/d$ from 2001–2003 (Colangelo 2007). Depth in the river channel varied within a range of 6 to 17 ft over the WY2002–WY2018 wet seasons with changing discharge at S-65A (the primary water control structure controlling flow to the Kissimmee River) and rainfall.

In the Kissimmee River, DO concentrations of 1 to 2 mg/L are stressful to centrarchids (bass and other sunfish), and concentrations below 1 mg/L can be lethal (Furse et al. 1996). Hypoxic and anoxic conditions also affect other aquatic organisms that depend on DO. Because reestablishment of pre-channelization fish and aquatic invertebrate communities is a primary goal of the KRRP (Koebel 2005, Glenn and Arrington 2005), DO concentration declines to 1 mg/L in the recovering ecosystem are a water management concern. A summary of current knowledge of the relationship of hypoxia and anoxia to water management in the Kissimmee River was published in the 2015 SFER – Volume I, Chapter 9 (Cheek et al. 2015).

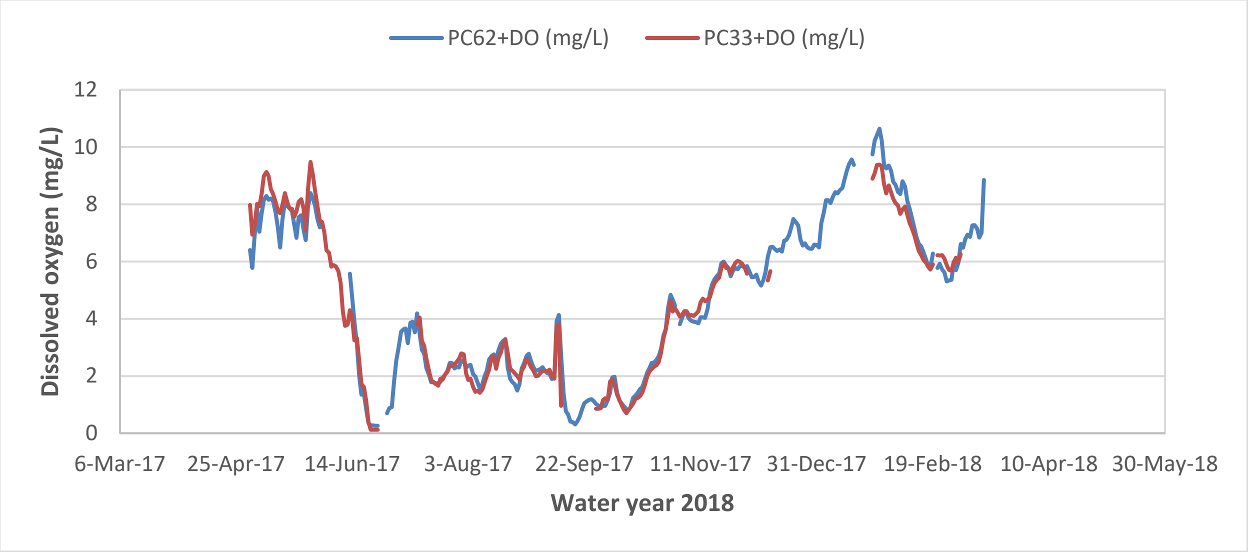


Figure 9-24. Daily mean DO concentrations in sampling stations PC33 and PC62 in the river channel of the Phase I Impact area in WY2018. For evaluation of Expectation 8, Component [d].

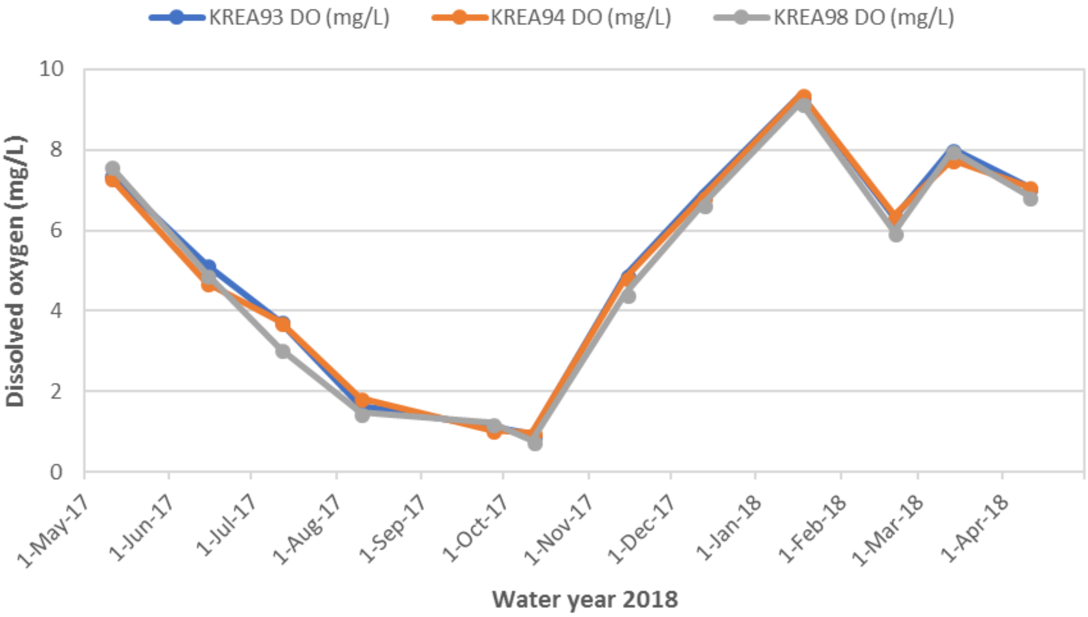


Figure 9-25. Monthly daytime DO concentrations in sampling stations KREA93, KREA94, and KREA98 in the river channel of the Phase I Impact area (Pool BC) in WY2018.

DO sag events start when the DO concentration declines below 2 mg/L and end when the DO concentration rises above 2 mg/L. WY2018 included two DO sag events in which the concentration of DO also declined below 1 mg/L (i.e., both were potentially lethal to centrarchids and would be expected to inhibit recovery of centrarchid populations [Chen et al. 2018]). Both events were associated with discharge increases caused by heavy rainfall in the UKB and LKB. The first event lasted 14 days (June 18–July 2, 2017) and was the more severe of the two, with a mean daily DO concentration below 1 mg/L for 12 days, a minimum concentration of 0.1 mg/L, and a fish kill observed. The second event was caused by Hurricane Irma and lasted for 40 days (September 8–October 18, 2017), with a mean daily DO concentration of 1.26 mg/L (**Figure 9-26**).

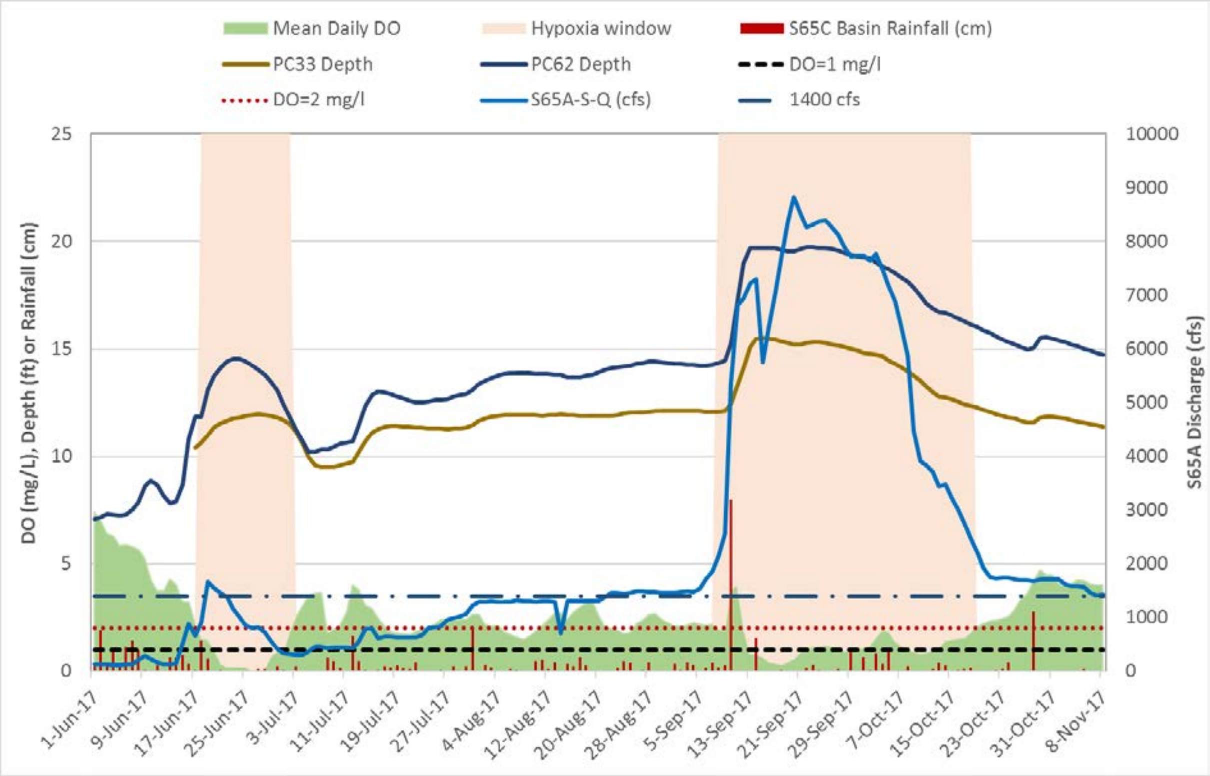


Figure 9-26. Hypoxic and anoxic event with mean daily DO in the river channel at PC33 and PC62 in relation to mean daily S-65A discharge, S65C basin rainfall, and river channel depth in wet season WY2018. Pink areas indicate periods of hypoxic or anoxic conditions.

The effects of rapid increases in upstream discharge on photosynthesis and respiration, either alone or in concert with local rainfall, can drive and sustain hypoxic/anoxic conditions in the Kissimmee River. This is hypothesized to occur when increases in flow and rainfall cause a rapid increase in water depth in the river and floodplain, reducing light penetration and disrupting photosynthetic aquatic biota (**Figure 9-27**). Additional factors likely involve mobilization of nutrients from soils as dissolved organic carbon (DOC), nitrogen (DON), and phosphorus (DOP) from the floodplain when it is inundated and in runoff from the floodplain to the river channel when flow is within channel bank. Such an influx of nutrients can increase rates of biochemical oxygen demand due to higher respiration (**Figure 9-27**). Other factors may include seepage of anoxic groundwater from the surficial aquifer system and dilution of oxygenated river channel water with anoxic water flowing from upstream (i.e., water from the C-38 canal in Pool A). District scientists continue to work to identify water management actions that may reduce the severity and duration of DO sag events in the Kissimmee River.

Since completion of Phase I construction in 2001, DO conditions as evaluated with the DO expectations have generally improved. However, isolated declines in DO resulting in periods of hypoxic (DO 1–2 mg/L) or anoxic (DO < 1 mg/L) conditions have occurred annually in the post-construction Kissimmee River as reported in previous SFERs (Koebel et al. 2016). For centrarchids in the Kissimmee River, DO concentrations of 1–2 mg/L are stressful and concentrations < 1 mg/L can be lethal (Furse et al. 1996, Bousquin et al. 2008). Hypoxic and anoxic conditions also may stress or kill other aquatic organisms, including invertebrates that depend on DO. These conditions often are most pronounced and severe during the wet season when rainfall followed by increases in upstream discharge to the Kissimmee River occurs after a prolonged period of low discharge (Cheek et al. 2015). Because of the potential for hypoxic and anoxic conditions to negatively affect the recovery of native fish and other aquatic organisms in the restoration area, they are viewed as a high-priority water management challenge for the KRREP (Koebel and Bousquin 2014).

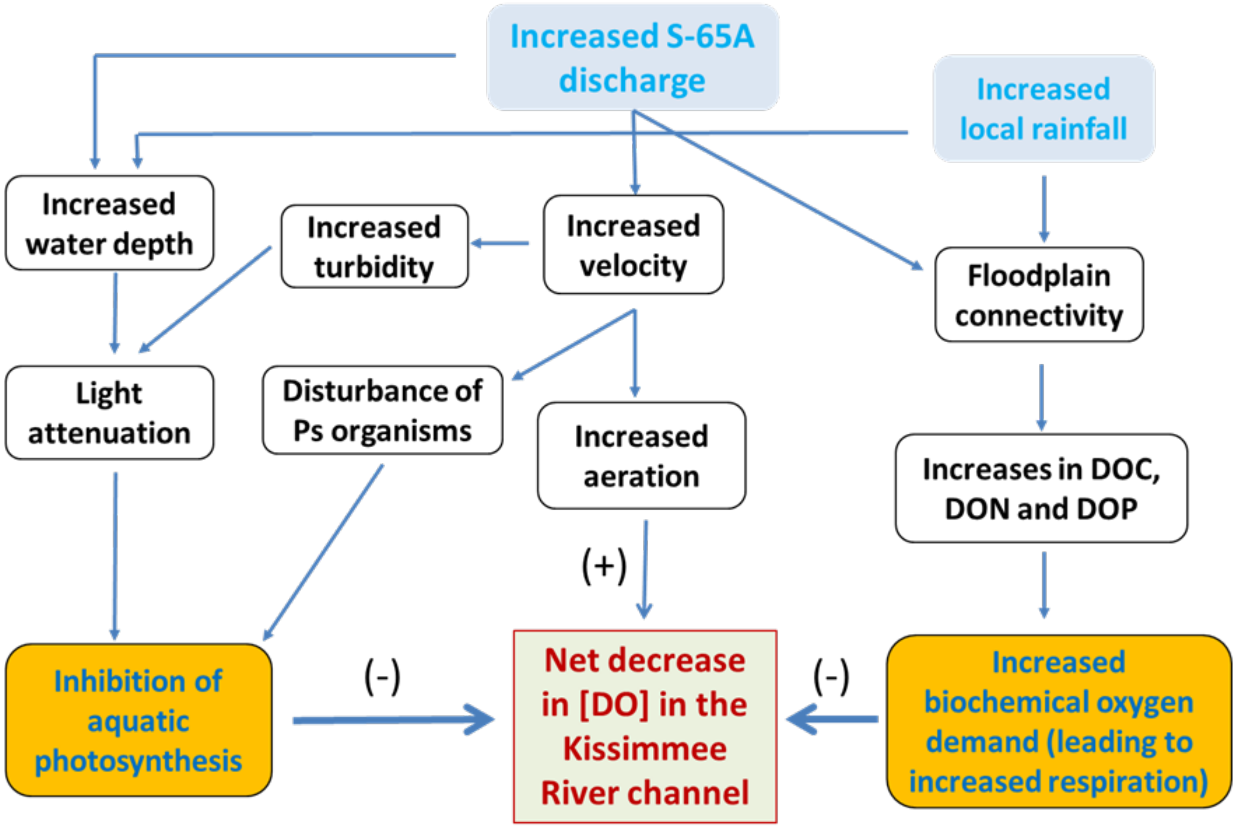


Figure 9-27. A diagram visualizing hypothesized effects of S-65A discharge and local rainfall on dissolved oxygen [DO] concentration in the Phase I area of the Kissimmee River in the wet season. Photosynthesis and respiration are two primary processes influencing [DO]. Symbol (+) indicates an increase in [DO] and symbol (-) indicates a decrease in [DO]. DOC, DON, and DOP are dissolved organic carbon, nitrogen, and phosphorus, respectively. Other processes and external factors also affecting [DO] are not shown in the diagram, including solar radiation, conductivity, water temperature, and groundwater impact.

During the 2017 wet season, the Kissimmee River was anoxic for portions of June and September; intermittent hypoxia occurred during the intervening period (**Figure 9-10C**). The first period of anoxia was associated with a confirmed fish kill. Additional information is provided earlier in the *Wet Season Dissolved Oxygen* subsection of the *2017 Wet Season Water Management Outcomes* section.

FLOODPLAIN VEGETATION

KRREP scientists developed expectations predicting coverage of wetland vegetation communities on the restored Kissimmee River floodplain (Carnal 2005a, b, c) based on historical areal coverage using data from the 1952-1954 pre-channelization vegetation map (**Figure 9-28**, map a; derived from Pierce et al. 1982). The expectations for overall wetland area and two dominant vegetation types, BLM and wet prairie, are enumerated in the following sections. These expectations refer to the entire project area and predict full response only after HRS is implemented. Because the project is not complete at the time of this writing, the expected values are compared with results for the Phase I area only.

A vegetation map based on 2015 aerial imagery of the Kissimmee River floodplain was completed in 2017, covering the Phase I construction area (**Figure 9-28**, map f). To evaluate interim (pre-project completion) responses of floodplain vegetation, the 2015 map was compared with previous maps (**Figure 9-28,** maps a–e) of floodplain vegetation for five time periods: 1952 (pre-channelization), 1974 (3 years following completion of channelization), 2003 (2 years following completion of Phase I), 2008 (7 years following completion of Phase I), and 2011 (10 years following completion of Phase I).

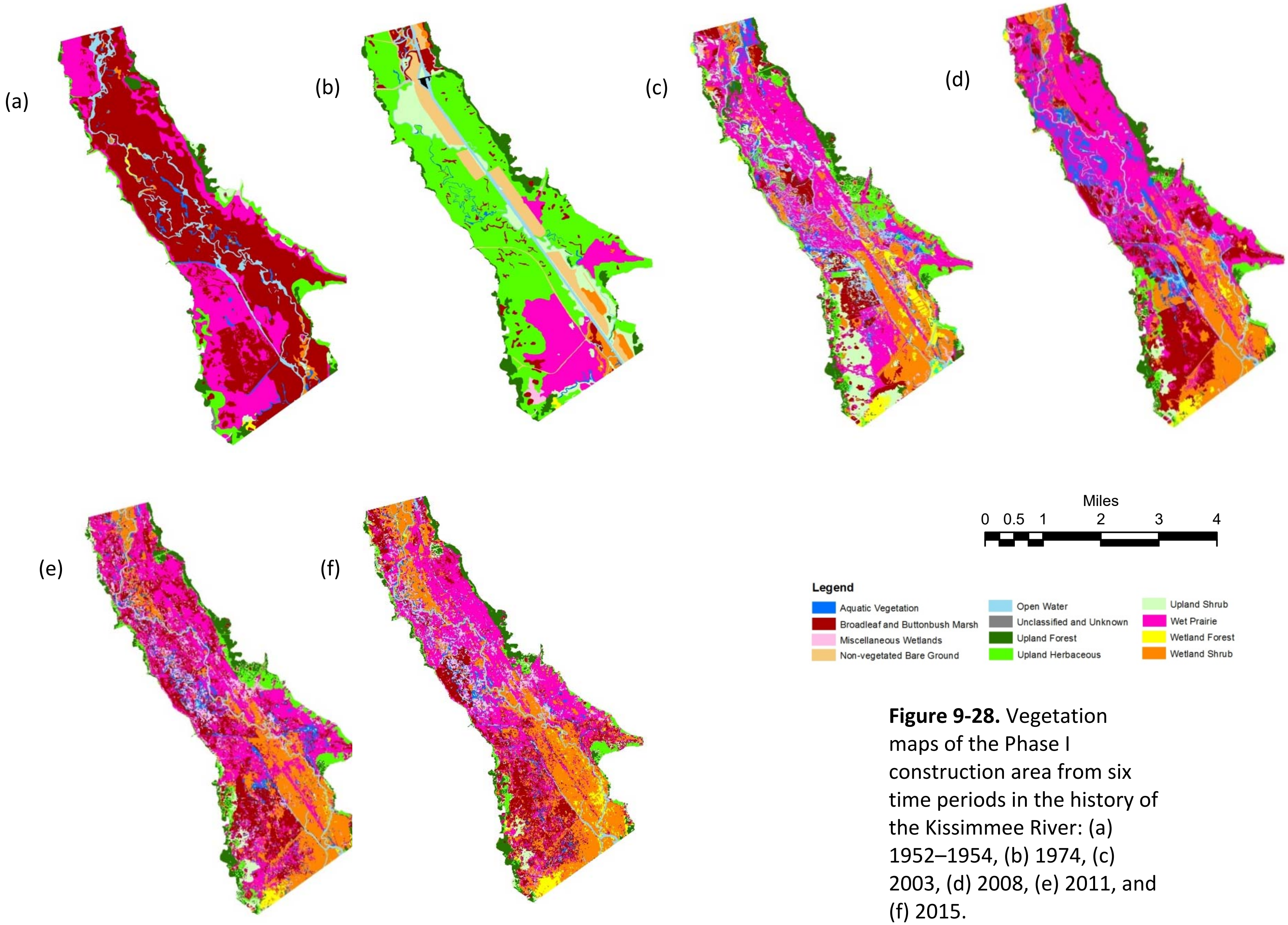


Figure 9-28. Vegetation maps of the Phase I construction area from six time periods in the history of the Kissimmee River: (a) 1952–1954, (b) 1974, (c) 2003, (d) 2008, (e) 2011, and (f) 2015.

Expectation 12

Wetland plant communities will cover > 80% of the area of the floodplain restored in Phases I–IV (Carnal 2005a).

After increasing to meet this expectation by 2008, total wetland plant community coverage in the Phase I floodplain remained steady at approximately 3,200 hectares (83%) between 2008 and 2011 and increased slightly to 3,250 hectares (84%) in 2015 (**Table 9-7**).

Table 9-7. Sum of area in hectares (and percent area) of vegetation types within the Phase I restoration area over five time periods.

	1952	1974	2003	2008	2011	2015
Broadleaf (including Buttonbush) Marsh						
Total	1,913	175	304	658	793	639
	(49.7%)	(4.6%)	(7.9%)	(17.1%)	(20.6%)	(16.6%)
Wet Prairie						
Total	1,186	525	1,270	1,513	1,167	1,136
	(30.8%)	(13.6%)	(33.0%)	(39.3%)	(30.3%)	(29.5%)
Wetland Shrub						
Total	36	104	637	706	734	1002
	(0.9%)	(2.7%)	(16.6%)	(18.3%)	(19.1%)	(26.0%)
Other Wetland						
Total	82	68	341	331	508	470
	(2.1%)	(1.8%)	(8.9%)	(8.6%)	(13.2%)	(12.2%)
Aquatics	61	36	136	241	173	109
	(1.6%)	(0.9%)	(3.5%)	(6.3%)	(4.5%)	(2.8%)
Miscellaneous Wetlands	9	26	76	25	298	264
	(0.2%)	(0.7%)	(2.0%)	(0.6%)	(7.8%)	(6.9%)
Wet Forest	12	6	129	65	37	97
	(0.3%)	(0.1%)	(3.3%)	(1.7%)	(0.9%)	(2.5%)
Total Wetlands						
Total	**3,216**	**872**	**2,553**	**3,208**	**3201**	**3247**
	(83.6%)	**(22.7%)**	**(66.4%)**	**(83.4%)**	**(83.2%)**	**(84.4%)**
Other Classes						
Total	631	2,975	1,294	639	646	600
	(16.4%)	(77.3%)	(33.7%)	(16.6%)	(16.9%)	(15.6%)
Non-Vegetated	0	385	1	0	3	1
	(0.0%)	(9.9%)	(0.0%)	(0.0%)	(0.1%)	(0.0%)
Open Water	210	176	373	183	104	175
	(5.5%)	(4.6%)	(9.8%)	(4.8%)	(2.7%)	(4.5%)
Upland	421	2414	920	456	539	424
	(10.9%)	(62.8%)	(23.9%)	(11.8%)	(14.0%)	(11.0%)
Overall Total Area						
	3,847	**3,847**	**3,847**	**3,847**	**3,847**	**3,847**

Expectation 13

BLM will cover at least 50% of the restored floodplain in Pools B, C, and D (Carnal 2005b).

BLM vegetation decreased in the latest period to approximately 639 hectares (17%) of floodplain area, down from 793 hectares (21%) in 2011 (**Table 9-7**). This expectation has not been met since initiation of the project.

BLM vegetation is a long-hydroperiod marsh vegetation type that, prior to channelization, was characteristic of lower elevations of the floodplain that were inundated for up to 7 months of the year. In the 2015 map, BLM vegetation continues to occupy an area well below its expected coverage level on the Phase I floodplain (50%), and it showed a marked reduction over the previous map. Inability to achieve suitably prolonged periods of floodplain inundation under the current regulation schedule is a dominant factor in the failure of BLM recovery, but competitive pressure from invasive plant species, including the wetland shrubs Carolina willow (*Salix caroliniana*) and primrose willow (*Ludwigia peruviana*), as well as invasive grasses such as West Indian marsh grass (*Hymenachne amplexicaulis*) also may be competing directly in BLM areas, as their occurrence adjacent to these areas appears to have increased over the period (L. Spencer, pers. obs.).

Expectation 14

Wet Prairie communities will cover at least 17% of the floodplain restored by Phases I–IV of the restoration project (Carnal 2005c).

Wet Prairie vegetation coverage exceeded this expectation, as it has since 2008, but has showed a slight decrease in areal coverage between 2011 and 2015. It now makes up about 1,136 hectares (30%) of the area, close to the 1,167 (still about 30%) reported in 2011 (**Table 9-7**). That Wet Prairie vegetation has higher coverage than occurred historically is primarily due to the shorter hydroperiods in the current system, which prevent BLM from occupying its historical range. A relatively new and notable issue related to Wet Prairie vegetation is the expansion of exotic wetland grasses, including para grass (*Urocloa mutica*) and West Indian marsh grass.

The largest coverage increase between 2011 and 2015 was in the category Wetland Shrub, which increased in area by about 6%. From field observations (L. Spencer, pers. obs.), this increase appears to be mostly because of expansion of Carolina willow populations, especially within the northern to central parts of the Phase I area (**Figure 9-28**, map f; **Table 9-7**). This expansion may be a natural expansion of the established populations of mature willows within the area. Also, from ground observations (L. Spencer, pers. obs.), the invasive exotic primrose willow seems to dominate the central floodplain in the southern portion of the Phase I area, closest to the S-65C water control structure (**Figure 9-28**, map f; **Table 9-7**). Relatively stable upstream water levels associated with the structure may have allowed this invasive species to out-compete native species in the area. The structure was removed in 2017. Once the HRS is implemented, conditions may be less favorable for primrose willow, and native vegetation may return to this area (Spencer and Bousquin 2014).

Efforts are under way to quantify the areal coverage of Carolina willow and primrose willow using photo interpretation of these communities in the 2015 imagery. In order to reverse the expansions of invasive species noted above using adaptive management, District personnel have been testing vegetation management techniques in some parts of the floodplain, including herbicide and fire used in different combinations to test their efficacy. So far, such treatments have been promising, but measurable reductions of invasive species over the long term will require further testing and application of an integrated approach. Beneficial changes in the coverage of invasive species may come about when restoration construction is completed and the HRS is implemented after 2020. Although near-continuous flow has been maintained in the river channel and the floodplain has been inundated intermittently during the 14 years that elapsed between completion of Phase I and the 2015 imagery, historical hydroperiods may not be closely approximated until the HRS is implemented. The changes in hydrology that will follow implementation of the HRS are expected to drive further changes in the coverage of vegetation types and these conditions should favor BLM vegetation in lower elevations of the floodplain.

IMPACT OF THE 2017 HYPOXIC EVENTS ON FISH IN THE KISSIMMEE RIVER

In the Kissimmee River, fish, especially gamefish, can be stressed when the DO concentration decreases below 2 mg/L (hypoxia) and may die when DO is < 1 mg/L (anoxia) (Furse et al. 1996). Since Phase I of construction for KRRP was completed in 2001, DO concentrations generally have improved (see the *Dissolved Oxygen* section earlier in this chapter), but prolonged periods of anoxic conditions continue to occur annually during the wet season. In 2014, KRREP began a new study to quantify fish populations in the river and their response to restoration construction and water management. Early in the 2017 wet season, there was an anoxic event associated with a fish kill. This section summarizes the impact of this event on fish, focusing on centrarchids, an important group of gamefish.

Methods

Beginning in 2014, fish were sampled annually on randomly selected transects in the Phase I (n = 12) and Phase IV (n = 10) restoration areas, where flow was restored in 2001 and 2009, respectively. Sampling was conducted during periods of within-bank flow water in May-June. Each transect was a 150-m segment of river shoreline. Fish were sampled by electroshocking each transect for approximately 15 minutes. The exact duration was used to calculate the BPUE for all species and two groups that included hypoxia-tolerant and hypoxia-intolerant species, using the classification of Trexler (1995) for Kissimmee River fishes. All stunned fish were identified, measured to the nearest millimeter of total length (TL), weighed to the nearest gram and released alive. Additional samples were collected in July and December 2017 to better understand how anoxic/hypoxic events are affecting fish populations in the Kissimmee River.

To evaluate the effect of the 2017 anoxic events, two important gamefish, largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*), were studied. The mean of BPUE calculated for each of the four years prior to the anoxic events were compared with the post-event mean of samples collected in July and December 2017 and spring 2018.

Results and Discussion

Largemouth bass and bluegill account for most of the centrarchid biomass collected in the Kissimmee River since 2014. Both species experienced substantial challenges during the 2017 wet season when exposed to anoxic conditions in June and again in September, following Hurricane Irma (see *Dissolved Oxygen* section above for more information on these hypoxic and anoxic events). Mean BPUE for largemouth bass was 7.1 kg/hr (±1.2 SE) for the four years preceding several anoxic/hypoxic events in the 2017 wet season; it decreased significantly to 0.6 kg/hr (±0.3 SE) after the events (ANOVA, F = 20.56, $p < 0.01$) (**Figure 9-29**). That few bass were recorded in post-crash sampling suggests recovery of the bass population may take years. For bluegill, BPUE averaged 2.2 kg/hr (±0.3 SE) prior to the first anoxic event then fell significantly to 0.05 kg/hr (±0.03 SE) immediately after the event. However, bluegill appear to have recovered as the mean BPUE of 1.59 kg/hr (±0.27 SE) for the winter 2017 and spring 2018 samples was not significantly less than the pre-event mean BPUE (ANOVA, F = 2.4, $p > 0.05$). (**Figure 9-30**).

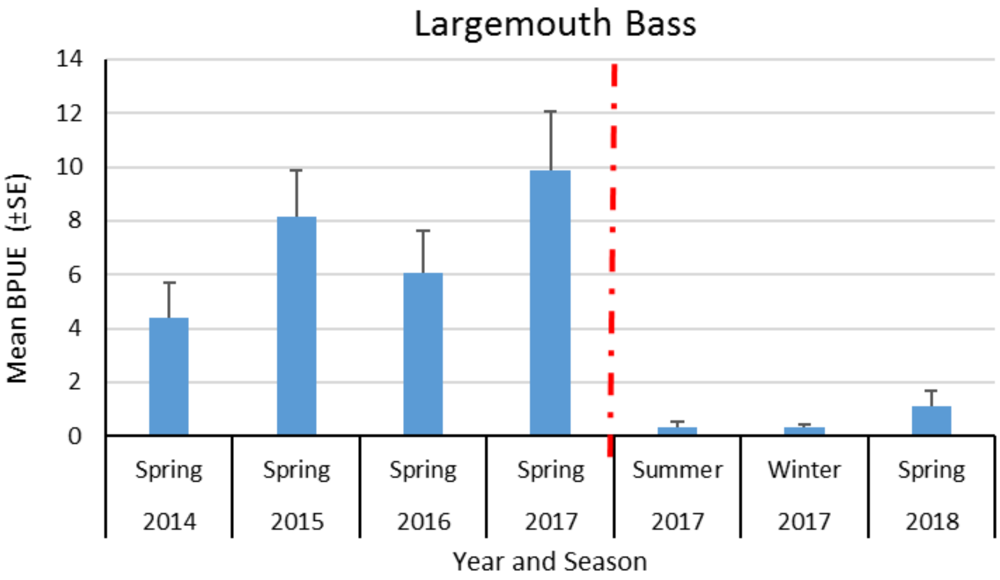


Figure 9-29. Mean biomass of largemouth bass (kg/hour ± S.E.) collected prior to and after two anoxic events (dissolved oxygen crash) that occurred during summer 2017. The bars to the left of the vertical red line represent data collected prior to the anoxic events and seasonal data collected after the anoxic events appear to the right of the red division line. Data were collected from 22 monitoring sites in the restored region (Phases I and IV) of the Kissimmee River.

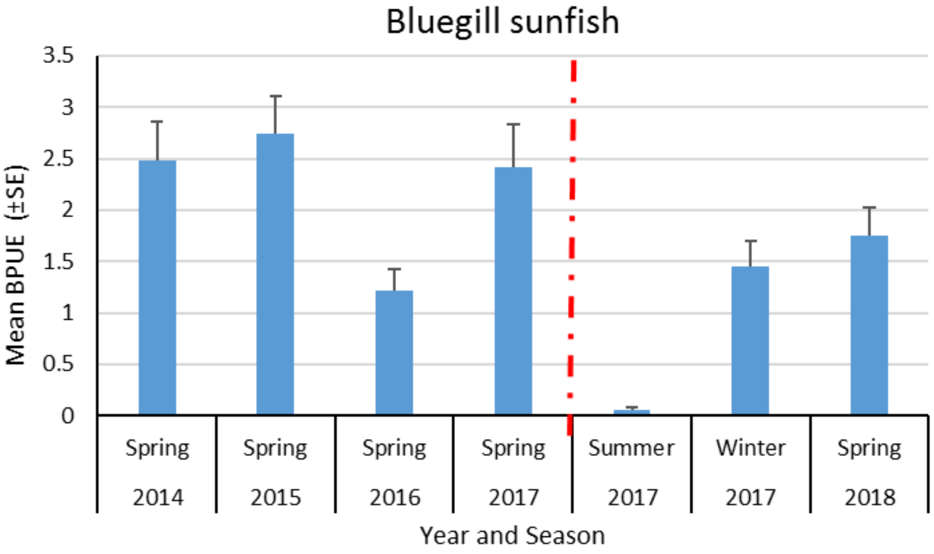


Figure 9-30. Mean biomass of bluegill (kg/hour ± S.E.) collected prior to and after two anoxic events (dissolved oxygen crash) that occurred during summer 2017. The bars to the left of the vertical red line represent data collected prior to the anoxic events and seasonal data collected after the anoxic events appear to the right of the red division line. Data were collected from 22 monitoring sites in the restored region (Phases I and IV) of the Kissimmee River.

To further evaluate the impacts of anoxic/hypoxic events on the river's fishery, fish species were divided into two groups based on their tolerance to low DO concentrations. Both groups, the intolerant (centrarchids) and tolerant (rough fish and exotics), experienced large reductions in mean BPUE during summer 2017, following the initial anoxic event. That even tolerant species declined suggests they were impacted, which may have been due to the rapid and extreme reduction in DO at the onset of the anoxic event. Prior to the event, mean BPUE values for the tolerant and intolerant groups were 38.9 kg/hr (±4.7 SE) and 11.3 kg/hr (±1.0 SE), respectively. Following the anoxic events, mean BPUE for the tolerant group was 23.1 kg/hr (±3.8 SE), while the intolerant group fell to 2.4 kg/hr (±0.35 SE). Both values were significantly less than the pre-event means. Since winter 2017, the tolerant group appears to be recovering more quickly than the intolerant group (**Figure 9-31**).

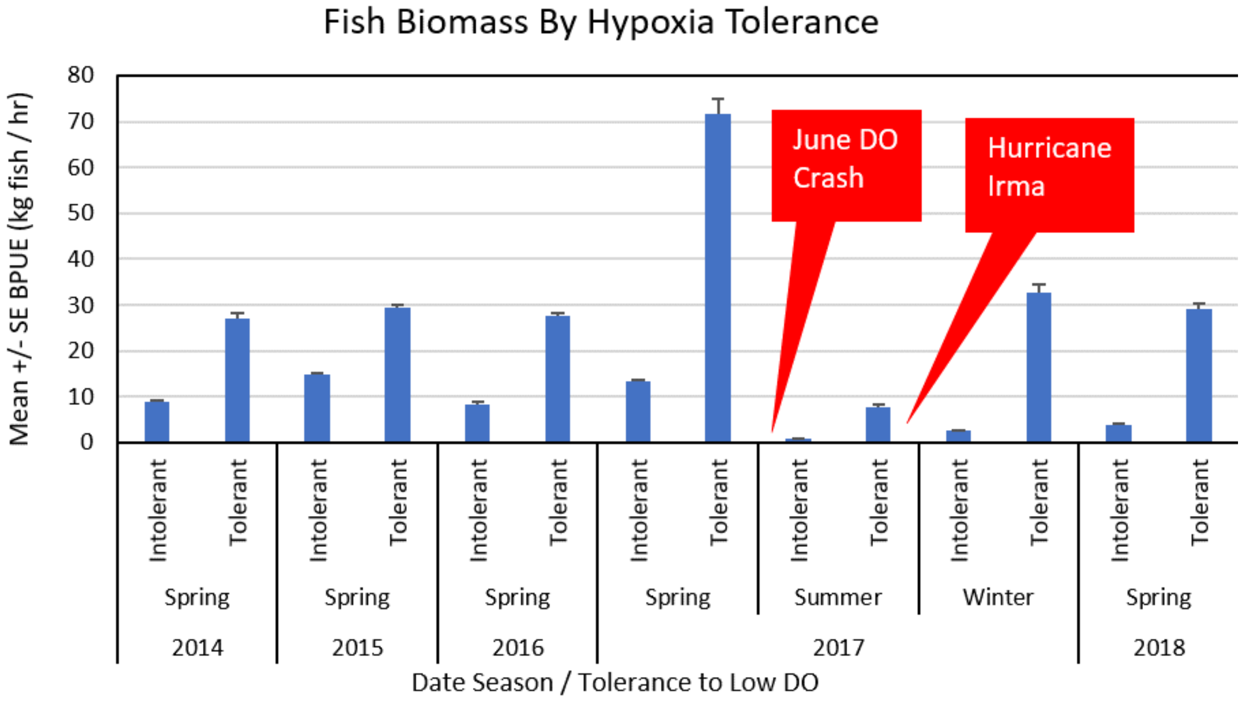


Figure 9-31. Biomass (kg/hr ± SE) of low DO intolerant centrarchids and low DO tolerant FGAR, bowfin, and exotic species by season and year (2014-2018).

In addition to requiring a sufficient DO concentration to survive and reproduce, many fish species in the Kissimmee River also use floodplain habitat for reproduction and feeding (Lee et al. 1980). The large-bodied species, including largemouth bass and bluegill, depend on shallow floodplain areas for spawning. Bass and bluegill are nest builders that prefer relatively shallow, open areas with sandy substrate. Largemouth bass tend to spawn during the spring (dry season) while bluegill can spawn during both the dry and wet (summer) seasons. Limiting or preventing access to floodplain habitat during the spawning season is likely to negatively impact the river's centrarchid population. The dry floodplain conditions typical during spring in the Interim Period may be inhibiting largemouth bass recovery. For bluegill, spawning season (summer) access to floodplain habitat during the 2017 wet season, which was due to prolonged floodplain inundation (roughly from mid-late August through early November, see *Hydrology* section earlier), may have helped the population recover from the impacts of the anoxic events of wet season 2017.

The District continues to work to reduce the severity and duration of Kissimmee River hypoxic events to the extent possible. It will be difficult for the river's fishery to show long-term improvement until DO conditions improve and proper floodplain inundation depths and frequencies that allow access to the floodplain during breeding season are established.

WADING BIRDS AND WATERFOWL

Birds are integral to the Kissimmee River floodplain ecosystem and highly valued by the public. While quantitative pre-channelization data are sparse, available data and anecdotal accounts suggest the system supported an abundant and diverse bird assemblage (National Audubon Society 1936–1959, FGFWFC 1957). Restoration is expected to reproduce the necessary conditions to support such an assemblage. Because many bird groups (e.g., wading birds, waterfowl) exhibit a high degree of mobility, they are likely to respond rapidly to restoration of appropriate habitat (Weller 1995). Detailed information regarding the breadth of the avian evaluation program and the initial response of avian communities to Phase I restoration can be found in Chapter 11 of the 2005 SFER – Volume I (Williams et al. 2005b) and in Cheek et al. (2014). The objective of this section is to highlight portions of the avian program for which data were collected during winter and spring 2017–2018 (i.e., dry season 2017-2018, mostly within WY2018), and compare recent data to the restoration expectations. Statistical significance was evaluated at $\alpha = 0.05$.

Wading Bird Abundance

Expectation 24

> *Mean annual dry season density of long-legged wading birds (excluding cattle egrets) on the restored floodplain will be ≥ 30.6 birds per square kilometer (birds/km^2; Williams and Melvin 2005b).*

Monthly aerial surveys were used to estimate foraging wading bird abundance. Prior to the restoration project, dry season abundance of long-legged wading birds in the Phase I restoration area averaged (±SE) 3.6 ± 0.9 birds/km^2 in 1997 and 14.3 ± 3.4 birds/km^2 in 1998. Since completion of Phases I, IVA, and IVB of restoration construction in 2001, 2007, and 2009, respectively, annual abundance has ranged from 102.3 ± 31.7 birds/km^2 to 11.0 ± 1.9 birds/km^2 (mean [2002–2018] = 41.5 ± 5.8 birds/km^2) (**Figures 9-32** and **9-33**). The long-term annual three-year running mean (2002–2018) is 41.1 ± 3.7 birds/km^2, significantly greater than the restoration expectation of 30.6 birds/km^2 (t-test, $p = 0.007$, SAS Institute 2016, Williams and Melvin 2005b). However, only the three-year running means for the periods 2002–2005 and 2004–2006 were significantly different from the restoration target of 30.6 birds/km^2 when examined on an annual basis (t-test, SAS Institute 2016). Mean monthly wading bird abundance within the restored portions of the river during the 2017–2018 season was 56.5 ± 9.0 birds/km^2, bringing the three-year (2016–2018) running average down slightly to 37.2 ± 12.1 birds/km^2, but still above the expected target value (**Figure 9-32**).

Wading bird abundance was high during the initial fall recession (November, December, and into mid-January), with ≥100 birds/km^2 observed during four separate surveys (**Figure 9-34**). Abundance estimates stayed close to the restoration target through mid-February, until numbers dropped to 21.6 birds/km^2 during the February 27 survey. The two surveys in March showed an increase in numbers, possibly due to the northward movement of spring migrants, before numbers fell below the target in late March through early May, at which point the floodplain was almost completely dry and unsuitable for foraging.

White ibis (*Eudocimus albus*) dominated numerically (59.6%), followed in order of abundance by great egret (*Ardea alba;* 10.5%), small white heron (snowy egrets [*Egretta thula*] and juvenile little blue heron [*Egretta caerulea*]; 10.1%), glossy ibis (*Plegadis falcinellus*; 6.8%), great blue heron (*Ardea herodias*; 5.7%), black-crowned and yellow-crowned night herons (*Nycticorax nycticorax* and *Nyctanassa violacea*, respectively; 3.1%), wood stork (*Mycteria americana*; 1.9%), small dark heron (tri-colored herons [*Egretta tricolor*] and adult little blue heron; 1.7%), and roseate spoonbill (*Platalea ajaja*; 0.7%)

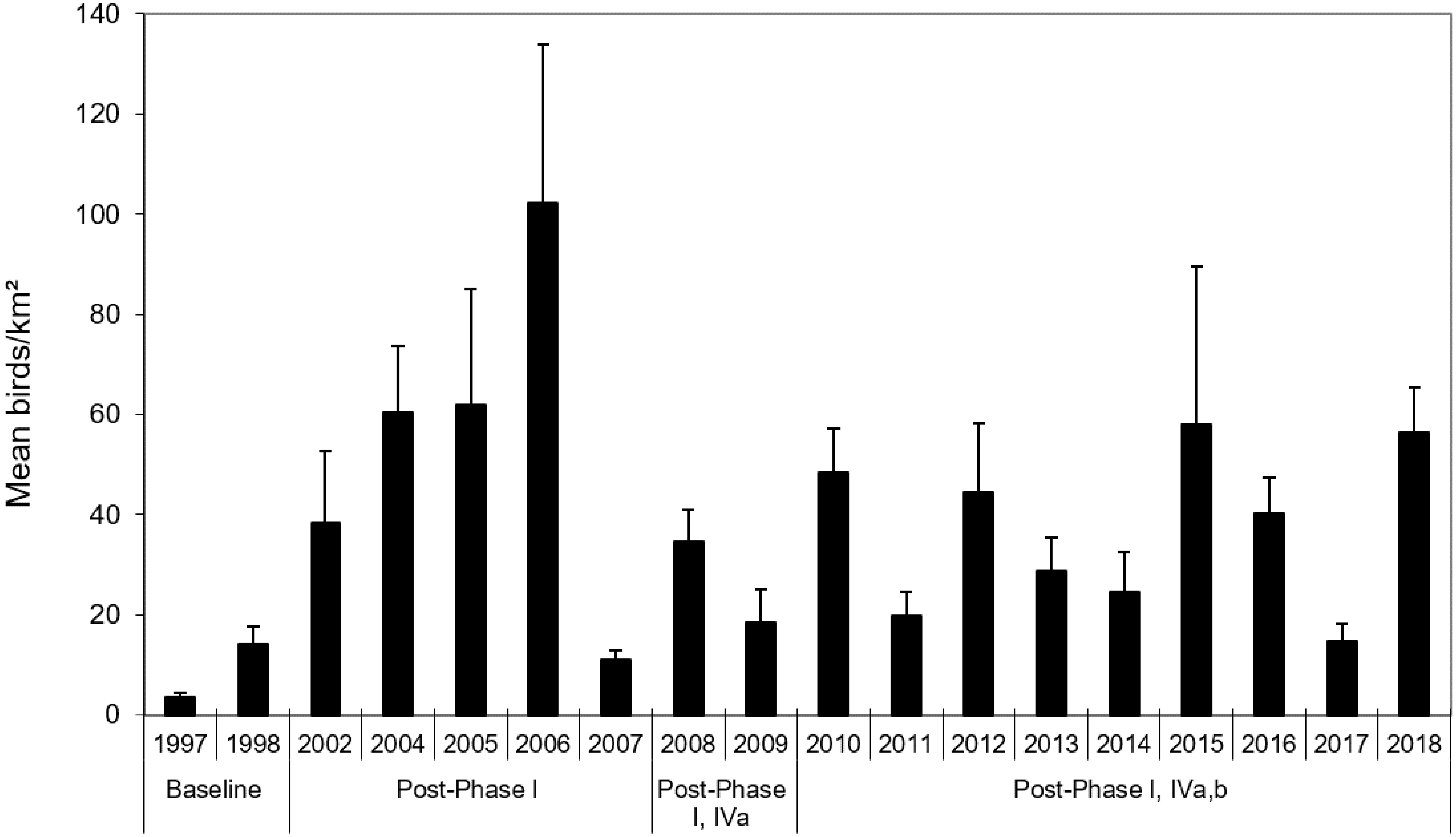


Figure 9-32. Baseline and post-Phases I, IVA, and IVB mean abundance ± SE of long-legged wading birds/km^2, excluding cattle egrets, during the dry season (December–May) within the 100-year flood line of the Kissimmee River.

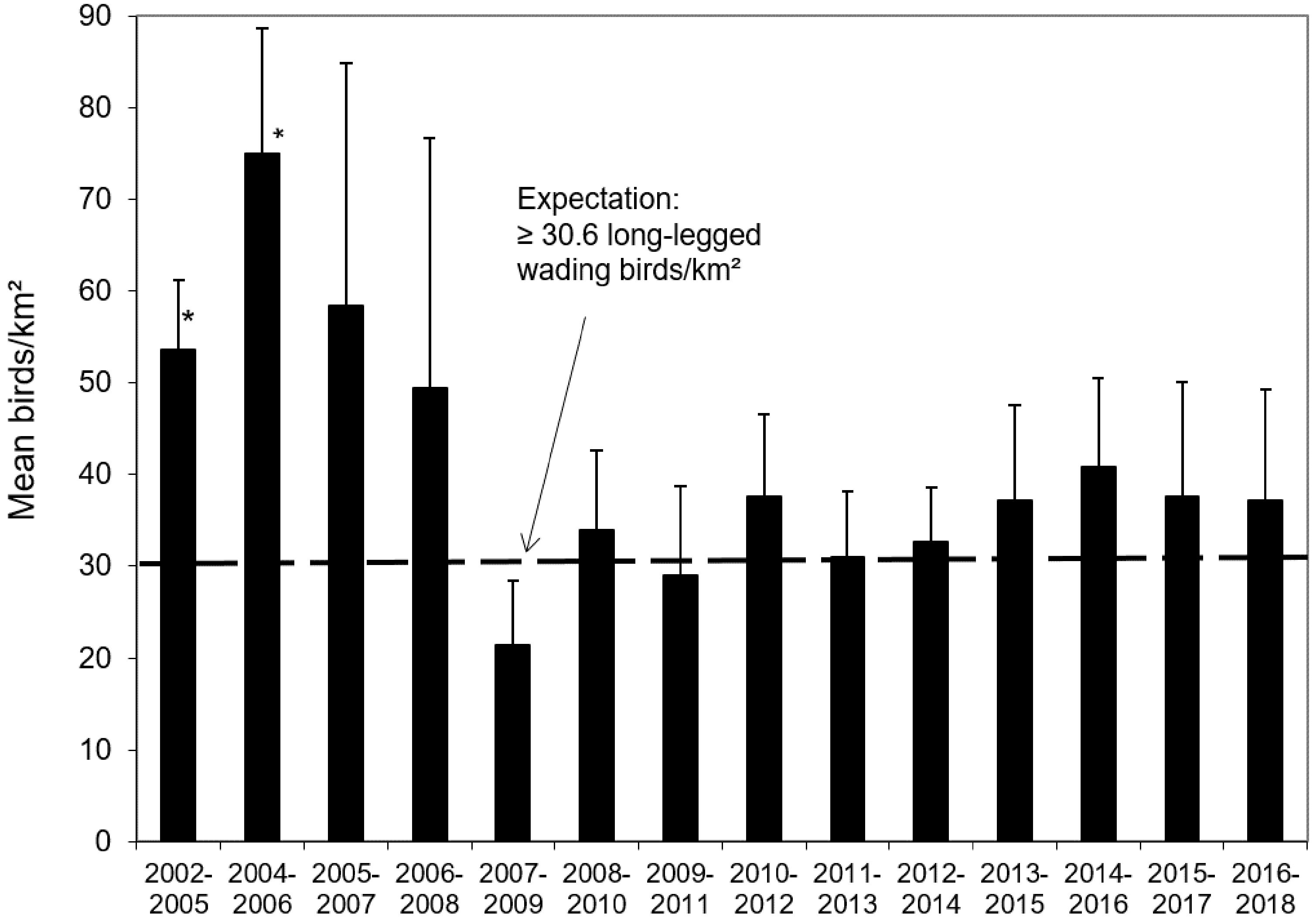


Figure 9-33. Post-restoration abundance as three-year running averages ± SE of long-legged wading birds/km^2, excluding cattle egrets, during the dry season (December–May) within the Phase I, IVA, and IVB restoration areas of the Kissimmee River. *Significantly greater than the restoration expectation of 30.6 birds/km^2 (t-test, SAS Institute 2016).

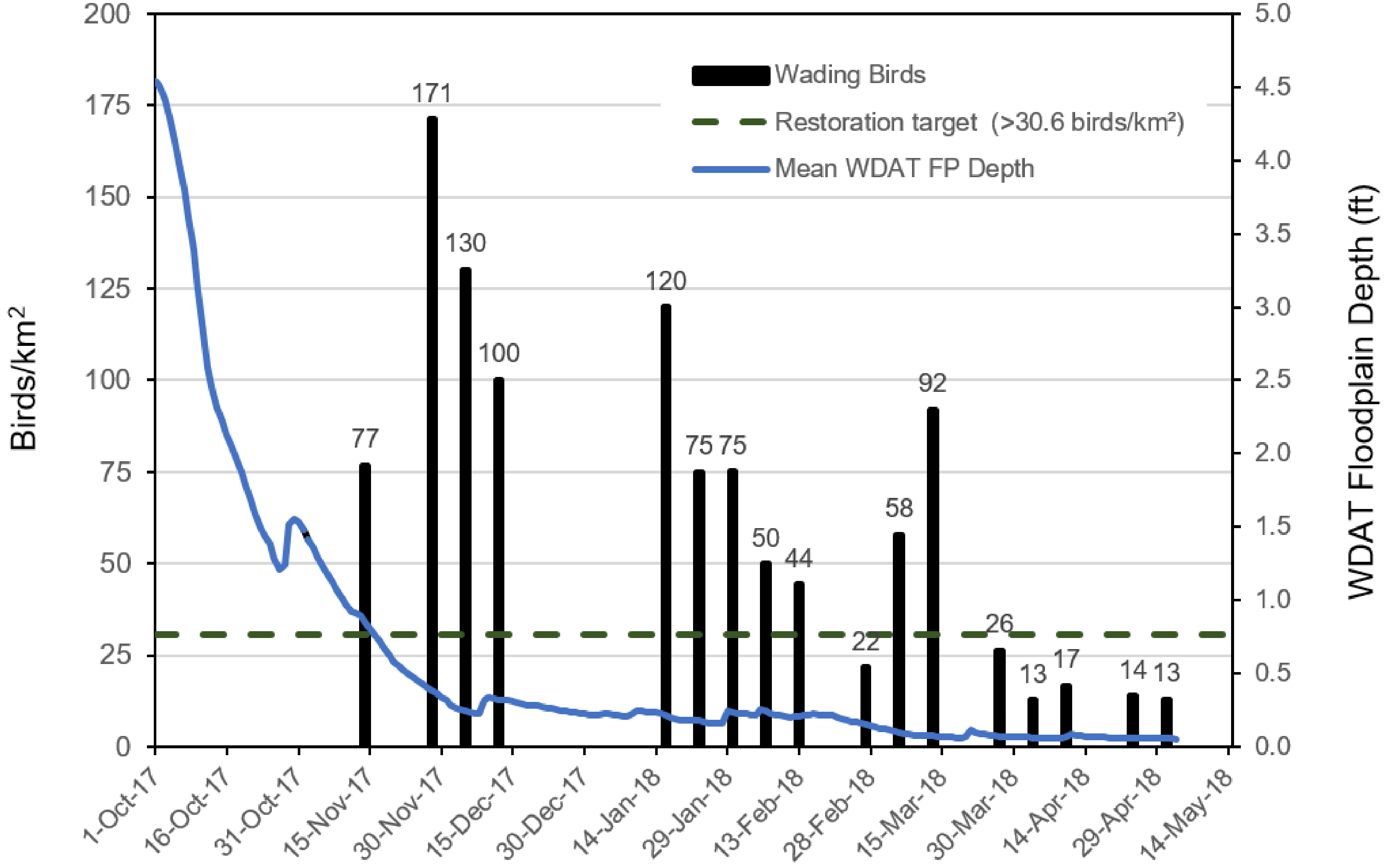


Figure 9-34. Wading bird abundance and mean floodplain depth in the KRRP area (Phases I, IVA, and IVB) during the 2018 dry season (December–May). Floodplain depth is obtained from the South Florida Water Depth Assessment Tool (WDAT; SFWDAT 2018).

Waterfowl Abundance

Expectation 25

> *Winter densities of waterfowl within the restored area of the floodplain will be ≥ 3.9 ducks per square kilometer (ducks/km^2). Species richness will be ≥ 13 (Williams et al. 2005a).*

Four duck species, blue-winged teal (*Anas discors*), green-winged teal (*A. crecca*), mottled duck (*A. fulvigula*), and hooded merganser (*Lophodytes cullulatus*), were observed during baseline aerial surveys. During the same period, casual observations of wood ducks (*Aix sponsa*) were made during ground surveys for other projects (Williams and Melvin 2005a). Mean annual abundance ±SE was 0.4 ± 0.1 ducks/km² in the Phase I area during the Baseline Period, well below the restoration expectation of 3.9 ducks/km². The long-term mean annual three-year running average (2002–2018) of waterfowl abundance is 11.1 ± 1.2 ducks/km², significantly greater than the restoration expectation of 3.9 ducks/km² (t-test, $p < 0.0001$, SAS Institute 2016). When examined on an annual basis, the three-year running averages for 2010–2012, 2011–2013, 2013–2015, and 2015–2017 were significantly greater than the restoration target of 3.9 ducks/km² (t-test, p-values = 0.038, 0.026, 0.033, 0.025, respectively, SAS Institute 2016).

Waterfowl abundance during the 2017–2018 survey was 42.0 ± 11.2 ducks/km², bringing the three-year (2016–2018) running average to 21.7 ± 10.1 ducks/km², although this was not significantly greater than the restoration target of 3.9 ducks/km² due to the large variability of annual means between years, in particular this season's extreme high (t-test, p-value = 0.11, SAS Institute 2016) (**Figures 9-35** and **9-36**). Since 2001, annual duck abundance has ranged from 42.0 ± 11.2 ducks/km^2 to 1.3 ± 1.3 ducks/km^2 (mean [2002–2018] = 12.8 ± 2.7 ducks/km^2) (**Figures 9-35** and **9-36**).

Waterfowl abundance during the 2017-2018 survey season was the greatest recorded since completion of Phase I restoration construction in 2001 (**Figure 9-35**). All surveys during the November-March target period were above the restoration target of 3.9 ducks/km^2, and five survey days had ≥ 72 ducks/km² (**Figure 9-37**). As is typical of aerial surveys of flocking species, the variance among survey dates was high, but the overall mean was above the restoration target because of large, patchily distributed flocks of mostly blue-winged teal (*Anas discors*). The large numbers of blue-winged teals observed on the floodplain this survey season may be the result of increased reproductive output in their northern breeding grounds during spring and summer 2017. The USFWS (2017) Waterfowl Population Survey estimated the blue-winged teal population was 7.9 ± 0.4 million birds, 18% above the 2016 estimate and 57% above the long-term average of 5.0 ± 0.04 million (USFWS 2017).

Teals (*Anas* sp.) dominated numerically (80.1%), followed in order of abundance by mottled duck (10.4%), unidentified ducks (9.2%, most likely teal), hooded merganser (0.2%), and northern shoveler (*Anas clypeata*; < 0.07%).

The American wigeon (*Anas americana*), northern pintail (*Anas acuta*), northern shoveler, ring-necked duck (*Aythya collaris*), and black-bellied whistling duck (*Dendrocygna autumnalis*) were not detected during baseline surveys but have been present following restoration construction. However, these species are not regularly observed, and the restoration target for waterfowl species richness (≥ 13 species total) has yet to be reached on an annual or cumulative basis. Blue-winged teal and mottled duck remain the two most commonly observed species, accounting for more than 93% of observations since 2001 (67.3 and 26.3%, respectively).

Restoration of the physical characteristics of the Kissimmee River and floodplain, along with the hydrologic characteristics of headwater inputs, is expected to produce hydropatterns and hydroperiods that lead to the development of extensive areas of wet prairie and BLM, two preferred waterfowl habitats (Chamberlain 1960, Bellrose 1980). Changes in the species richness and abundance of waterfowl within the restoration area likely are directly linked to the development of floodplain plant communities and the faunal elements they support, particularly populations of aquatic invertebrates (Harris et al. 1995). Extrinsic factors such as annual reproductive output on summer breeding grounds and local and regional weather patterns also may play a role in the speed of recovery of the waterfowl community.

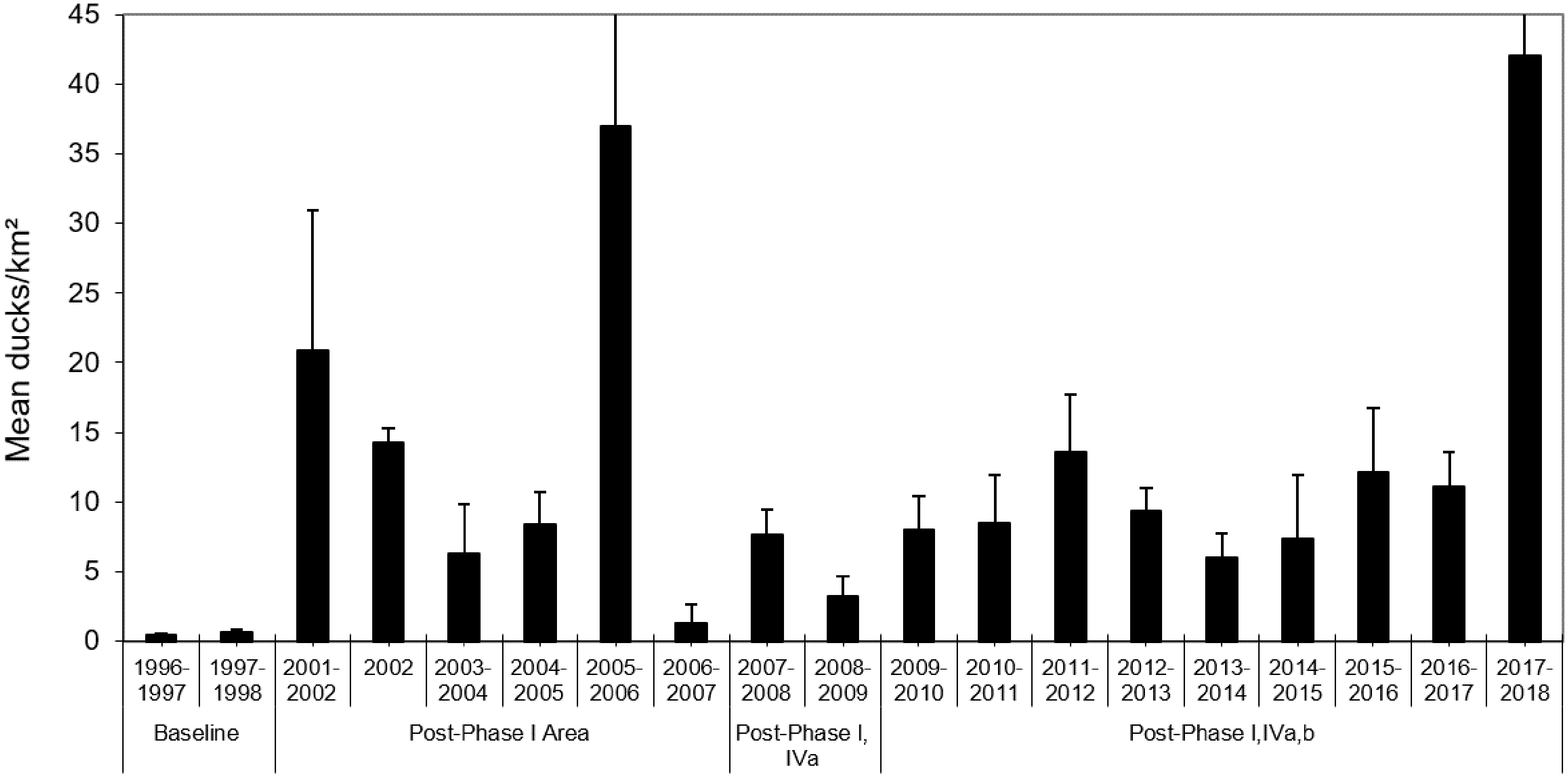


Figure 9-35. Baseline and post-Phases I, IVA, and IVB mean abundance ±SE of ducks during winter (November–March) within the 100-year flood line of the Kissimmee River. Baseline abundance was measured in the Phase I area prior to restoration. Measurement of post-restoration abundance began approximately nine months following completion of Phase I.

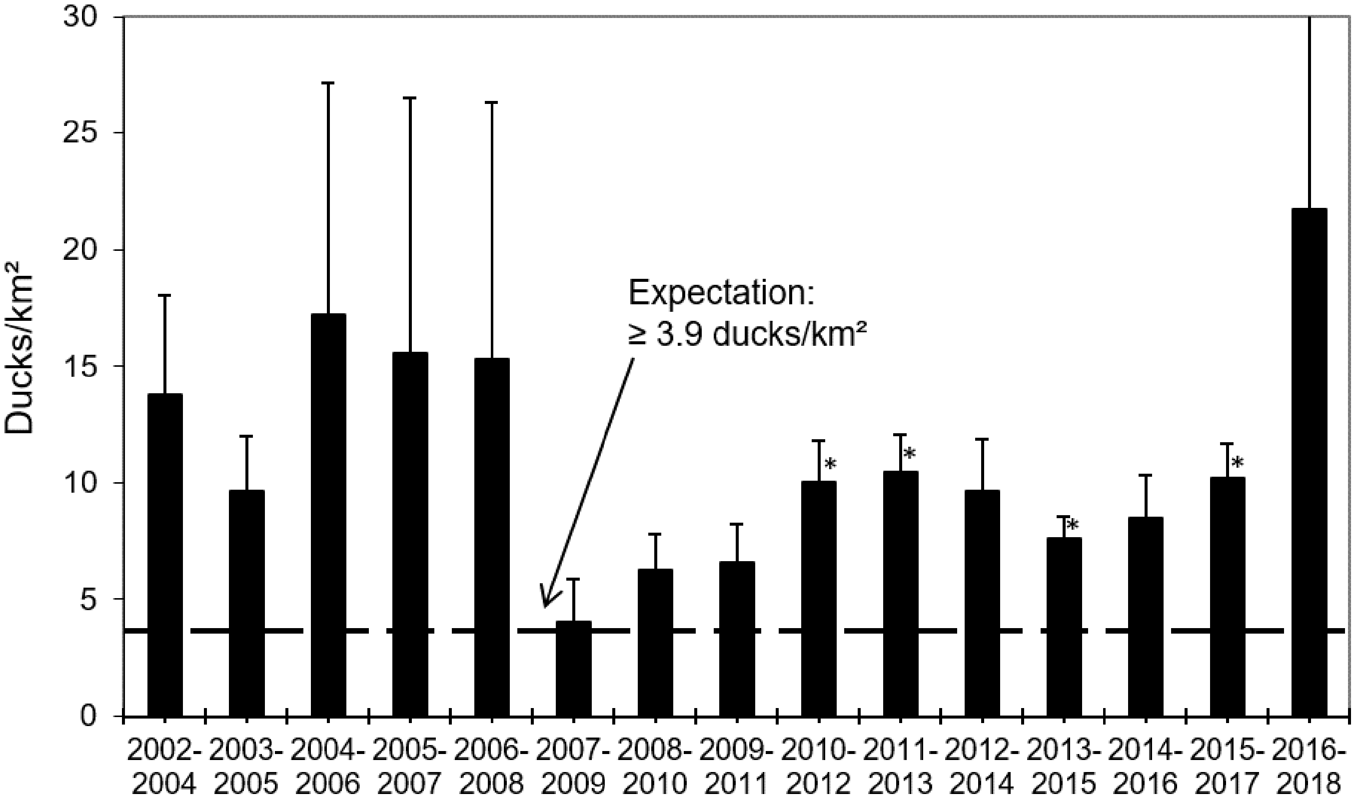


Figure 9-36. Post-restoration abundance as three-year running averages ±SE of ducks/km^2 during the winter (November–March) within the Phase I, IVA, and IVB restoration areas of the Kissimmee River.
*****Significantly greater than the restoration expectation of 3.9 ducks/km² (t-test, SAS Institute 2016).

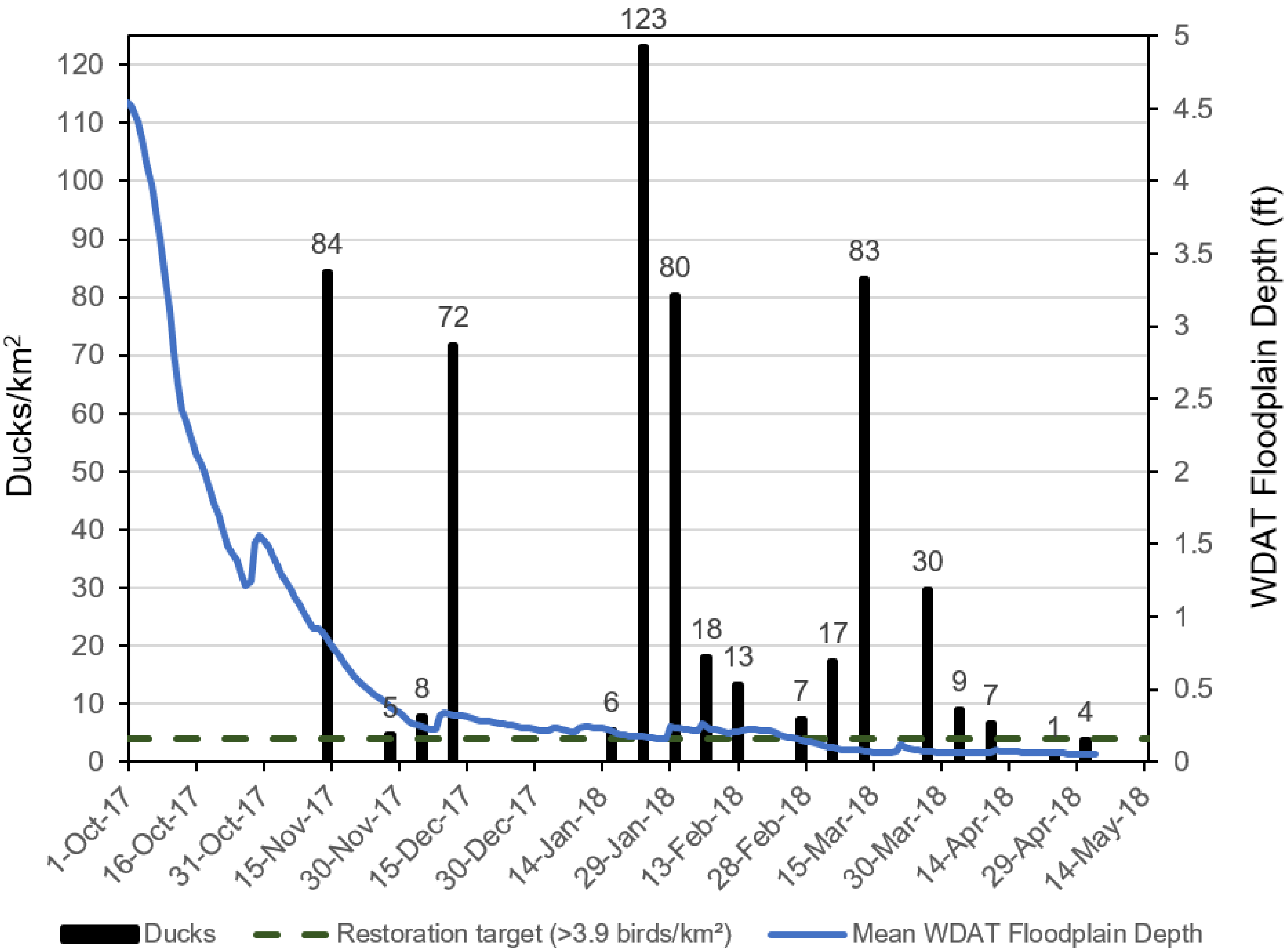


Figure 9-37. Duck abundance and mean floodplain depth in the KRRP area (Phases I, IVA, and IVB) during the 2017-2018 dry season (December 2017–May 2018). Source of floodplain depth data is SFWDAT (2018).

Wading Bird Nesting Colonies

Expectation

No formal expectation has been established for wading bird nesting colonies.

As part of the KRREP, SFWMD performed five surveys (March 27, April 10, May 15, May 29, and June 6, 2018) of known wading bird nesting colonies in Lake Kissimmee, along the Kissimmee River, and in Lake Istokpoga while also searching for previously undocumented colonies en route. The nest numbers reported here represent the maximum number of nests for each species observed, although the peak of nesting may not have been captured during the survey dates. It is likely the nests for a relatively small number of dark-colored wading birds, such as little blue heron (*Egretta caerulea*), glossy ibis (*Plegadis falcinellus*), tricolored heron (*Egretta tricolor*), yellow-crowned night heron (*Nyctanassa violacea*), and black-crowned night heron (*Nycticorax nycticorax*), were undercounted during the aerial surveys because of their lower visibility from above (Frederick et al. 1996). Thus, the colony totals presented in **Tables 9-8** and **9-9** are considered conservative. Nest fate and nesting success were not monitored.

Eight colonies were active during the 2018 season within the KRRP area, Kissimmee River Pool E, and Lakes Istokpoga and Kissimmee (**Tables 9-8** and **9-9**, **Figure 9-38**). Combined, the colonies were dominated by white ibis nests (2,505), followed by smaller numbers of cattle egret (1,745), great egret (934), small dark herons (53), great blue heron (38), small white herons (5), and wood stork (7). The largest of these colonies was Bumblebee Island in Lake Istokpoga (3,025), followed by Rabbit Island (Lake Kissimmee) (1,249), Pool E Spoil Island North (410), Pool E Spoil Island South (230), Lempkin Creek Retention Pond (152), Lake Kissimmee floating mat (105), Long Cypress Slash (Pool E) (104), and River Ranch C-38 (12) (**Figure 9-38**).

Like last season, no colonies occurred within 10 km of the partially restored portions of the Kissimmee River, but several occurred in unrestored portions of the river, north, east, and south of the restoration area (**Figure 9-38**). It is unclear whether any of the nesting birds in the colonies utilize the KRRP area for essential foraging during breeding, although it is unlikely due to the long foraging flight distance from the active colonies. Most foraging by nesting birds within the KRRP area would have occurred prior to early April, at which point most of the floodplain became dry and was unsuitable for foraging.

Most nesting of aquatic wading bird species and cattle egrets continues to occur outside of the KRRP area on islands in the UKB and Lake Istokpoga. To date, only one colony of aquatic bird species (S-65C Boat Ramp colony, not active since 2013) has formed within 5 km of the partially restored portion of the Kissimmee River, and during most years it has contained fewer than 50 nests of aquatic bird species. The continued small numbers of aquatic bird species nesting along the restored portion of the river suggests prey availability on the floodplain is not yet sufficient to support the completion of breeding during the nesting season (January–June). Prey availability is not only the density and abundance of prey, but also other environmental factors that can limit birds' access to suitable prey, including prey size and type, water depth, vegetation type, and seasonality (Gawlik 2002). So although results from throw trap sampling on the floodplain indicate prey density and biomass are sufficient to sustain wading bird foraging during the breeding season, other limiting factors may be precluding wading bird nesting on the floodplain such as individual prey size and type, seasonality of suitable water depths for foraging, and suitable nesting substrate (Koebel et al. 2017).

Table 9-8. Peak (maximum) number of wading bird nests within the KRRP area [a], 2003–2018. Sites were surveyed during March, April, May, and June 2018.

Year	Bird Species or Grouping [b]										Total Nests	Total Colonies	Nests of Aquatic Species [c]
	CAEG	GREG	WHIB	GBHE	SMDH	GLIB	BCNH	SMWH	WOST	ROSP			
2003	20	-	-	-	-	-	-	-	-	-	20	1	0
2004	-	-	-	-	-	-	-	-	-	-	0	0	0
2005	-	81	-	-	-	-	-	-	-	-	81	2	81
2006	500	133	-	9	-	-	-	-	-	-	642	4	142
2007	226	-	-	-	1	-	-	-	-	-	227	1	1
2008	-	2	-	4	-	-	-	-	-	-	6	1	6
2009	240	126	-	27	14	-	-	-	-	-	407	3	167
2010	891	35	-	31	37	-	-	-	-	-	994	2	103
2011	751	14	-	35	35	-	-	8	-	-	843	2	92
2012	1,202	-	-	18	108	-	-	18	-	-	1,346	2	144
2013	599	33	-	37	-	-	-	-	-	-	669	5	70
2014 [d]	5	23	-	28	1	-	-	-	-	-	57	5	52
2015	-	94	-	31	-	-	-	-	-	-	125	4	125
2016 [e]	291	316	-	20	-	-	-	-	-	-	627	4	336
2017	540	143	50	13	-	-	-	-	-	1	747	5	207
2018	1,264	484	416	33	53	-	-	5	7	-	2,262	7	998

a. KRRP Area sites include the Headwaters Lakes and colonies within approximately 10 km of the C-38 canal/backfill, including multiple Kissimmee Prairie sites, Bluff Hammock, Cypress West, Oak Creek Marsh, C-38 Caracara Run, Chandler Slough East, Chandler Slough New, Chandler Slough, Cypress West, Orange Grove, Orange Grove NW, Orange Grove SW, Pine Island Slough, S-65C Boat Ramp, S-65C Structure, S-65D Boat Ramp, and Seven Mile Slough, Pool E Spoil Island, S-65E colony, and Lemkin Creek Retention Pond.

b. Key to Species and Groupings:

CAEG = cattle egret (*Bubulcus ibis*)
GREG = great egret (*Ardea alba*)
WHIB = white ibis (*Eudocimus albus*)
GBHE = great blue heron (*Ardea herodias*)
SMDH = small dark heron (little blue heron [*Egretta caerulea*] and tricolored heron [*Egretta tricolor*] combined)
GLIB = glossy ibis (*Plegadis falcinellus*)
BCNH = black-crowned night heron (*Nycticorax nycticorax*)
SMWH = small white heron (snowy egret and juvenile little blue heron combined)
WOST = wood stork (*Mycteria americana*)
ROSP = roseate spoonbill (*Platalea ajaja*)

c. Excludes cattle egrets.

d. Expanded survey effort in 2014.

e. Reduced survey effort in 2016 but results from the Rabbit Island colony in Lake Kissimmee were added to the table this year.

Table 9-9. Peak (maximum) number of wading bird nests within Lake Istokpoga (Bumblebee Island), 2010–2018. Site was surveyed during March and May 2018.

Year	Bird Species or Grouping [a]									Total Nests	Total Colonies	Nests of Aquatic Species [b]
	CAEG	GREG	WHIB	GBHE	SMDH	GLIB	BCNH	SMWH	WOST			
2010	103	325	110	75	-	-	-	-	-	613	1	510
2011	381	200	50	45	-	-	-	-	-	676	1	295
2012	75	175	-	75	-	-	-	-	-	325	1	250
2013	250	343	-	55	-	-	-	-	-	648	1	398
2014	658	210	75	55	-	-	-	-	-	998	1	340
2015	434	180	829	-	-	-	-	-		1,443	1	1,009
2016	355	171	1,296	25	-	-	-	-	-	1,847	1	1,492
2017	10	124	818	35	1	6	-	4	-	998	1	988
2018	481	450	2,089	5	-	-	-	-	-	3,025	1	2,544

a Key to Species and Groupings:

CAEG = cattle egret (*Bubulcus ibis*)
GREG = great egret (*Ardea alba*)
WHIB = white ibis (*Eudocimus albus*)
GBHE = great blue heron (*Ardea herodias*)
SMWH = small white heron (snowy egret and juvenile little blue heron [*Egretta tricolor*] combined)
GLIB = glossy ibis (*Plegadis falcinellus*)
BCNH = black-crowned night heron (*Nycticorax nycticorax*)
SMDH = small dark heron (little blue heron and tricolored heron [*Egretta caerulea*] combined)
WOST = wood stork (*Mycteria americana*)

b. Excludes cattle egrets.

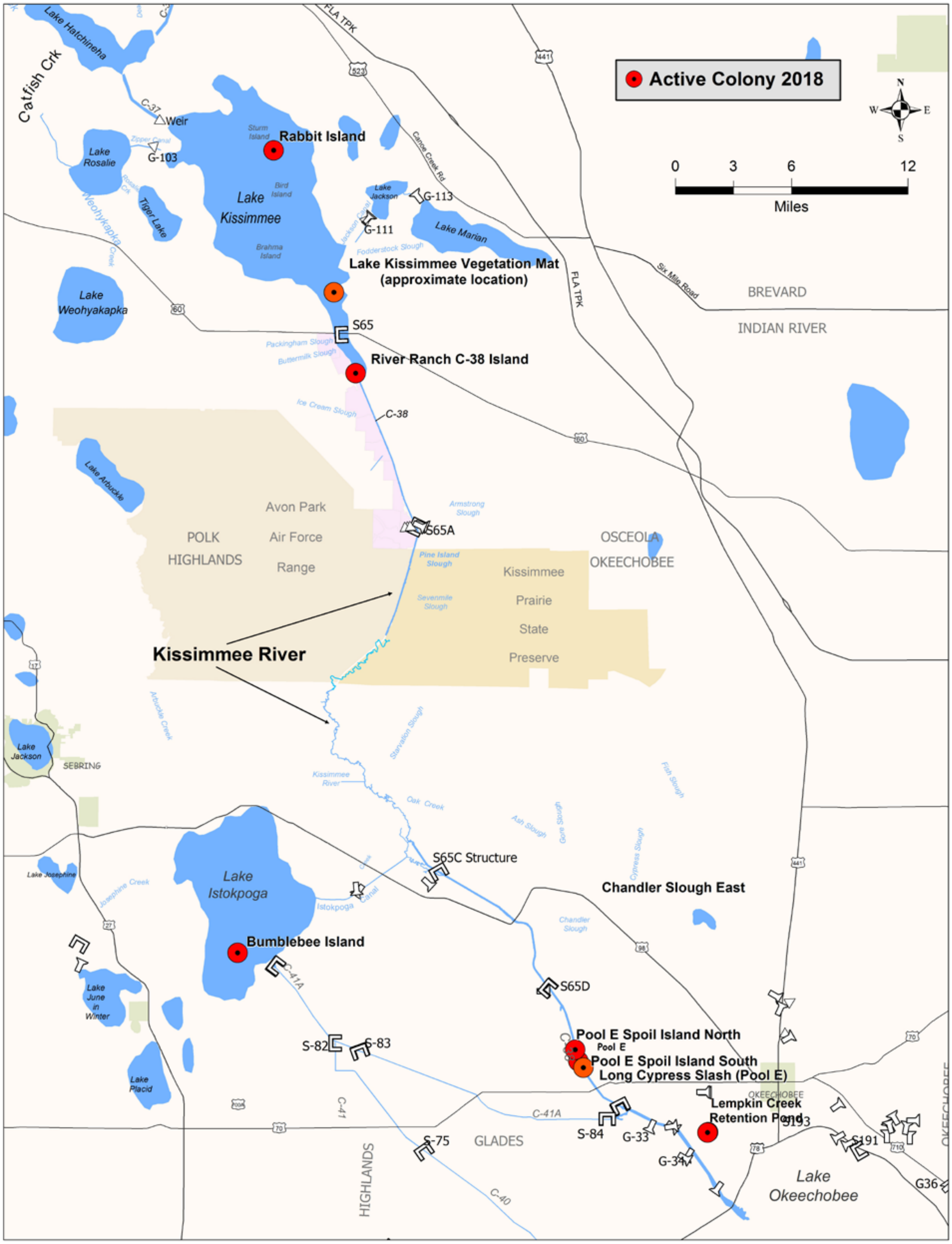


Figure 9-38. Nesting colony locations in Lake Kissimmee, Lake Istokpoga, and within the KRRP area (i.e., within approximately 10 km of the C-38 canal backfill) during 2018.

During the Interim Period (2001-2018), floodplain inundation during the wet season has been more intermittent and floodplain stage has been receding earlier in the year and much faster than historically seen during the dry season (**Figures 9-17**, **9-18**, and **9-20** in *Hydrology* section earlier). This has caused the floodplain to become drier earlier in the breeding season, when birds are beginning to select nesting colony sites, and nearly completely dry before nesting waders would be at their typical peak of foraging intensity while feeding nestlings. Thus, potential breeding wading birds in the system may be cueing in on suitable environmental conditions outside of the Kissimmee River floodplain where water levels and prey availability are more predictable and consistent during the dry season recession. Another possible factor preventing breeding colony site formation within the restoration area is lack of suitable habitat conditions during the January-June breeding season (e.g., woody substrate surrounded by water, nesting materials, nearby foraging areas) because of the more frequent recession events (White et al. 2005).

While foraging conditions on the floodplain can become optimal for wading birds during certain times of the year (see the *Wading Bird Abundance* subsection earlier in this section), the timing and magnitude of floodplain inundation and recession currently is not optimal for rookery formation due to operational constraints and other demands on water management. Implementation of the HRS in 2020 will allow water managers to more closely mimic the historical stage and discharge characteristics of the river, presumably leading to better hydrologic conditions for wading bird nesting colonies.

UPPER KISSIMMEE BASIN PROJECTS

KCOL AND UKB MONITORING AND ASSESSMENT PROJECT

The KCOL and UKB Monitoring and Assessment Project involves data collection, evaluation, and reporting to support the District’s mission to manage and protect water resources. The monitoring also contributes to the assessment of the Kissimmee River Headwaters Revitalization Project (HRP), which—under the HRS—will increase storage in the Headwaters Lakes to improve timing and volume of flow to ensure KRRP hydrologic success. Together, these products support management decisions and are used to determine whether management intervention is required or whether the ecosystem is responding as intended to management actions. Key focus areas include the following:

- Data collection and evaluations to define relationships between hydrology and the lake littoral vegetation response to seasonal water level conditions.
- Coordination with agency and environmental stakeholders to ensure non-redundant and complementary data collection and evaluation; to annually report on ecological conditions within the KCOL and UKB; and to facilitate information sharing and identification of emerging issues and concerns.

The scope of this year’s report includes an overview of watershed assessment, monitoring, and research results. The results provide an overview of ecological conditions and water quality trends in the UKB by combining data and information from SFWMD’s monitoring activities with those of KCOL partner agencies.

MONITORING HEADWATERS REVITALIZATION AND THE UKB

The HRP was designed to increase storage in the Headwaters Lakes to provide appropriate flow patterns to the Kissimmee River and floodplain upon completion of KRRP construction. The increased storage that results due to higher maximum regulatory stages are expected to improve the quantity and quality of littoral habitat in the Headwaters Lakes. The HRS will increase regulatory stages and change the operating schedule for S-65, which controls discharge from and stage the Headwaters Lakes.

Vegetation Monitoring

Monitoring vegetation within the existing littoral zones and up to future lake regulation elevations is necessary to estimate the effects of the HRS in the Headwaters Lakes on the quantity and quality of littoral habitat and document vegetation changes (USACE 1996). The need for vegetation monitoring was identified in the UKB Monitoring and Assessment Project (initiated in October 2010) to address data gaps and knowledge uncertainties determined during development of the KCOL Long-Term Management Plan (SFWMD et al. 2011). By combining monitoring efforts between these projects, expected improvements from the HRP can be better isolated from other management activities in the UKB, and monitoring efforts can be expanded to include wildlife responses in the future.

Currently, there are two vegetation monitoring studies on the KCOL that will fill these needs. The first is a District project that involves tracking changes in specific plant community types over time and documenting any distributional shifts up or down slope if they occur. The second is an FWC project that involves quantifying specific littoral communities via aerial imagery on a 3-5-year rotation in the major KCOL water bodies. Currently, the FWC is considering new methods for this project, including use of satellite imagery. Updated methods will be described and any new results will be presented in future versions of this report.

Permanent SFWMD Monitoring Stations

Long-term, permanent monitoring stations were established on three of the major water bodies in the KCOL (East Lake Tohopekaliga, Lake Tohopekaliga, and Lake Kissimmee) in early 2015, and sampled annually in August from 2015 through 2017. Lake Kissimmee is the only lake that will have a different regulation schedule under the HRS, while Lake Tohopekaliga and East Lake Tohopekaliga will serve as control lakes for comparison. Additional monitoring stations may be added to other Headwaters Lakes in the future, including Lakes Cypress or Hatchineha, or in the expansive Gardner Cobb Marsh that historically connected the Headwaters Lakes. The permanent monitoring stations include belt transects set perpendicular to shore in the upper reaches of the littoral zone.

Methods

Three interrupted belt transects (Baker et al. 1987) have been established perpendicular to shore between the low and high water elevations of the current regulation schedules. On Lake Kissimmee, the transects extend upslope to what will be the high-water elevation under the HRP regulation schedule. Perpendicular to each transect, two rectangular, 1-m × 2-m quadrats were sampled 1 m from the transect at each 0.5-ft elevation break (e.g., Frahn et al. 2014), totaling 7 sampling locations (2 subsamples each) on each transect for Lake Tohopekaliga and East Lake Tohopekaliga, and 11 sampling locations for Lake Kissimmee (**Figure 9-39**). Plant species abundance is visually estimated using modified Daubenmire (1959) cover classes in the late summer/fall of each year (Bousquin and Colee 2014). All transects were placed in grazed or mowed shorelines (plots at higher elevations extend into areas where vegetation is kept short by mowing or grazing).

Samples from 2015-2017 were grouped via cluster analysis using Sorenson distance measure and flexible beta of -0.25, and species representative of each cluster were identified via indicator species analysis (ISA; Tichý and Chytrý 2006). ISA identifies species most frequently found in one group and rarely in other groups but are not necessarily dominant in terms of areal coverage. The number of clusters was chosen based on the ISA with the lowest average p-values and highest number of significant indicator species (McCune and Grace 2002). For analyses (except species diversity), species were grouped within a genus according to their wetland indicator status (e.g., *Rhynchospora* or *Cyperus*; Facultative Wet or Obligate) to reduce variability, and others were grouped at genus level because of dominance of one species and no differences in wetland indicator status among the genera (e.g., *Fimbristylis* spp.).

Results and Discussion

The cluster and ISA analyses suggested three distinct communities for East Lake Tohopekaliga and Lake Tohopekaliga and four communities for Lake Kissimmee, distributed along a depth gradient (**Table 9-10**). The shallowest group's indicator species on Lake Kissimmee were at a higher elevation than the other lakes because samples there are collected up to 1.5 ft above the current regulated high pool (top of the regulation schedule). This group's indicators were pasture grass (*Paspalum notatum*) and pasture weeds (*Richardia scabra, Scoparia dulcis*). The community near the top of the regulation schedule was similar among all lakes, with indicators grasses (*Andropogon* spp.), big carpetgrass (*Axonopus furcatus*), and sedges (*Rhynchospora* spp.) identified in all three. Similarly, mid-elevations were dominated by *Luziola fluitans* and the lowest elevations were dominated by pickerelweed (*Pontederia cordata*) on all three lakes.

Species diversity showed consistent trends among the three lakes, with peaks in the number of species occurring 0.5 to 1.0 ft below the top of the regulation schedules (**Figure 9-40**). Lake Kissimmee was the only lake where samples were collected above the elevation of the current regulation schedule, showing declines in diversity as habitats transitioned to upland. All lakes had similar numbers of species, with peak diversity occurring at roughly 30 species per 2 m^2.

Grouping species by wetland indicator status (Lichvar et al. 2012) also revealed consistent trends between lakes. The driest group sampled, those normally occurring in uplands (Facultative Upland), did not occur frequently within elevations of the regulation schedules but were present at moderate coverages at the highest elevation, i.e., the maximum regulated stage (**Figure 9-41**). Facultative species, those occurring within and above wetland elevations, extended downslope in each of the lakes about 1.5 feet below the regulation maximum, and on Lake Kissimmee, also up to about 1.5 feet above the regulation maximum. Facultative Wet indicators showed fairly consistent trends, with the highest abundances at mid-elevations and the lowest at the deepest and shallowest ends of the transects. One Facultative Wet species, torpedograss (*Panicum repens*), an exotic species that can grow in a wide range of conditions, caused some inconsistencies on Lake Tohopekaliga, where its abundance is moderate to dense even at lower elevations. For example, usually dominant Obligate species (like pickerelweed) at lower elevations had reduced cover values on Lake Tohopekaliga due to abundant torpedograss in some areas. Nonetheless, there were consistent patterns between the lakes of generally high coverage of Obligate species at low elevations, with abundance declining linearly with increases in elevation.

Baseline conditions of littoral zone vegetation are presented here using species abundance and diversity data to describe the composition and distribution of shoreline plant communities. Future changes in the Headwaters Lakes' regulation schedules should be reflected in the trends shown through shifts in where peak abundance or peak diversity occurs on the shoreline elevation gradient. Results also indicate similarities between the lakes' littoral zone vegetation. On every lake, water stage is represented by the same indicator species or group of species. In the future, focal species could be used to expand monitoring efforts. Peaks in diversity or abundance occur at about the same elevation, although the peaks may occupy a wider or narrower zone depending on the lake sampled (perhaps due to differences in seasonal water level fluctuation or other fine-scale hydrological variations). These and other analyses specific to community or species abundance will be important in assessing how operations for the restored Kissimmee River affect habitats upstream of the project and will help guide future water management decisions.

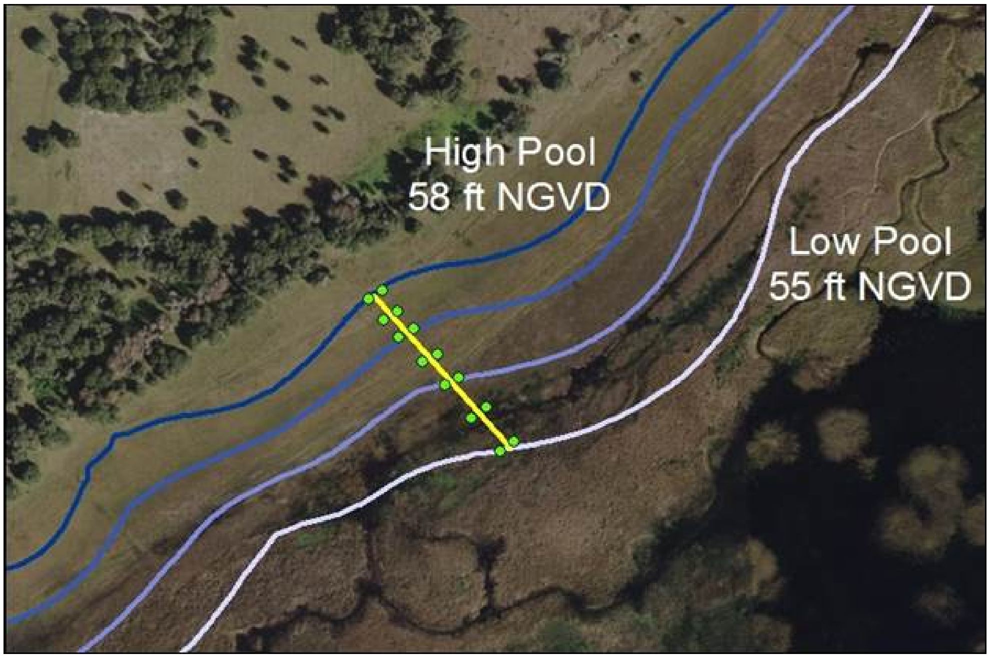


Figure 9-39. Example of line transects (yellow line) and subsamples (green dots) are shown to demonstrate approximate locations spanning 58-55 ft NGVD29 elevation contours on East Lake Tohopekaliga, or the maximum and minimum of the annual regulation schedule.

Table 9-10. Groups identified by cluster analysis for each lake, their general location on the shoreline elevation gradient, and indicator species for each.

Elevation	Lake **Kissimmee**	Lake **Tohopekaliga**	**East** Lake **Tohopekaliga**
Upland	*Paspalum notatum* *Richardia scabra* *Scoparia dulcis*	Not applicable	Not applicable
High Pool	*Andropogon* spp. *Rhynchospora* spp. *Eragrostis atrovirens* *Axonopus furcatus*	*Axonopus furcatus* *Cyperus* spp. *Centella asiatica* *Andropogon* spp. *Rhynchospora* spp.	*Rhynchospora* spp. *Axonopus furcatus* *Andropogon* spp.
Mid	*Luziola fluitans* *Panicum repens*	*Luziola fluitans*	*Luziola fluitans*
Low Pool	*Pontederia cordata* *Alternanthera philoxeroides*	*Pontederia cordata* *Typha* spp.	*Typha* spp. *Pontederia cordata*

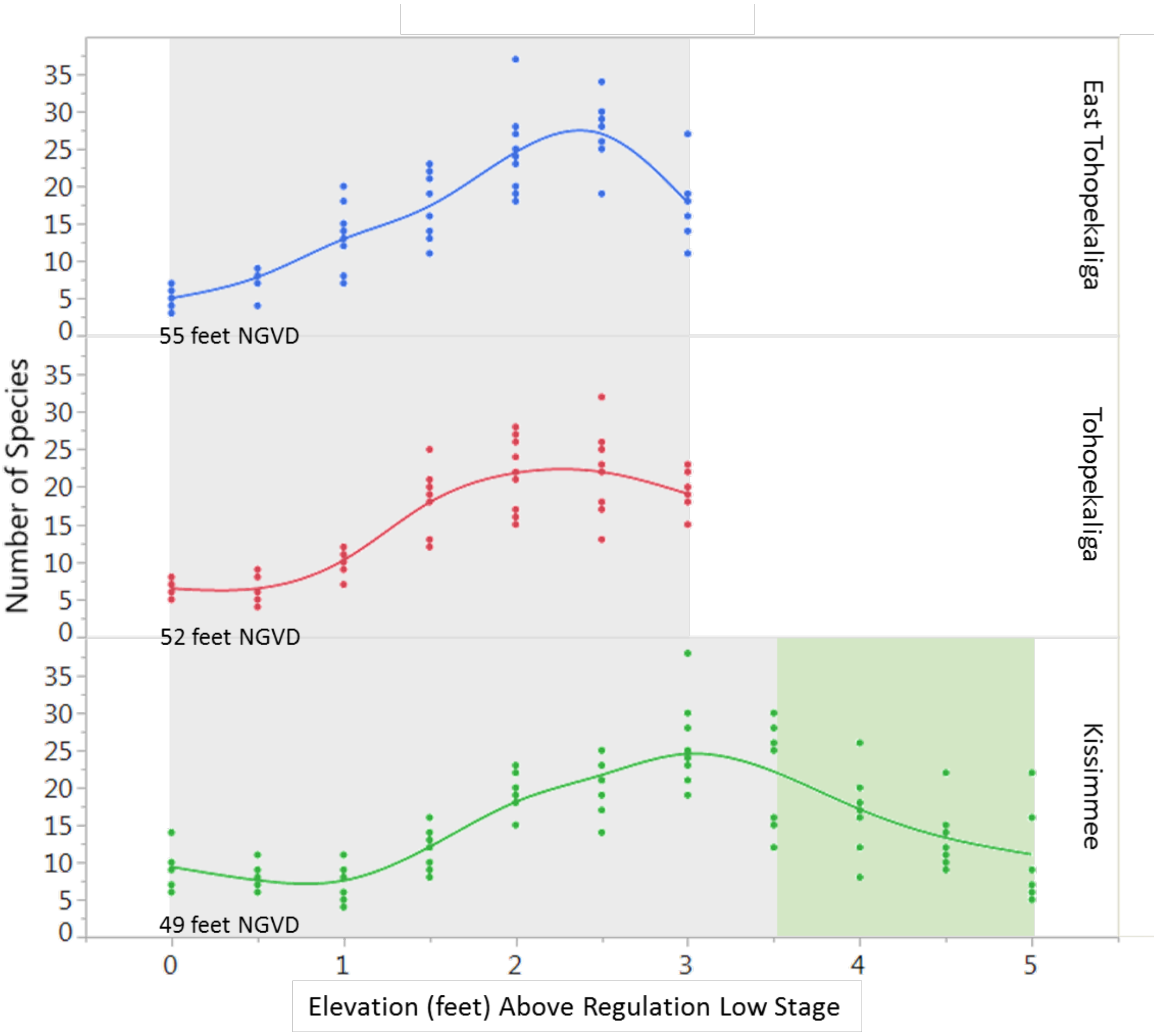


Figure 9-40. Number of species by elevation on transects in each of the study lakes during annual samples from 2015-2017. Gray boxes represent the elevations of the current regulation schedule, and green represents the future regulation expansion on Lake Kissimmee upon completion of Kissimmee River Restoration. Regulation schedules vary seasonally from 55-58 ft NGVD29 on East Lake Tohopekaliga, 52-55 ft NGVD29 on Lake Tohopekaliga, and 49-52.5 ft NGVD29 on Lake Kissimmee. Smoother lines with lambda = 0.05 are shown fit through the data points.

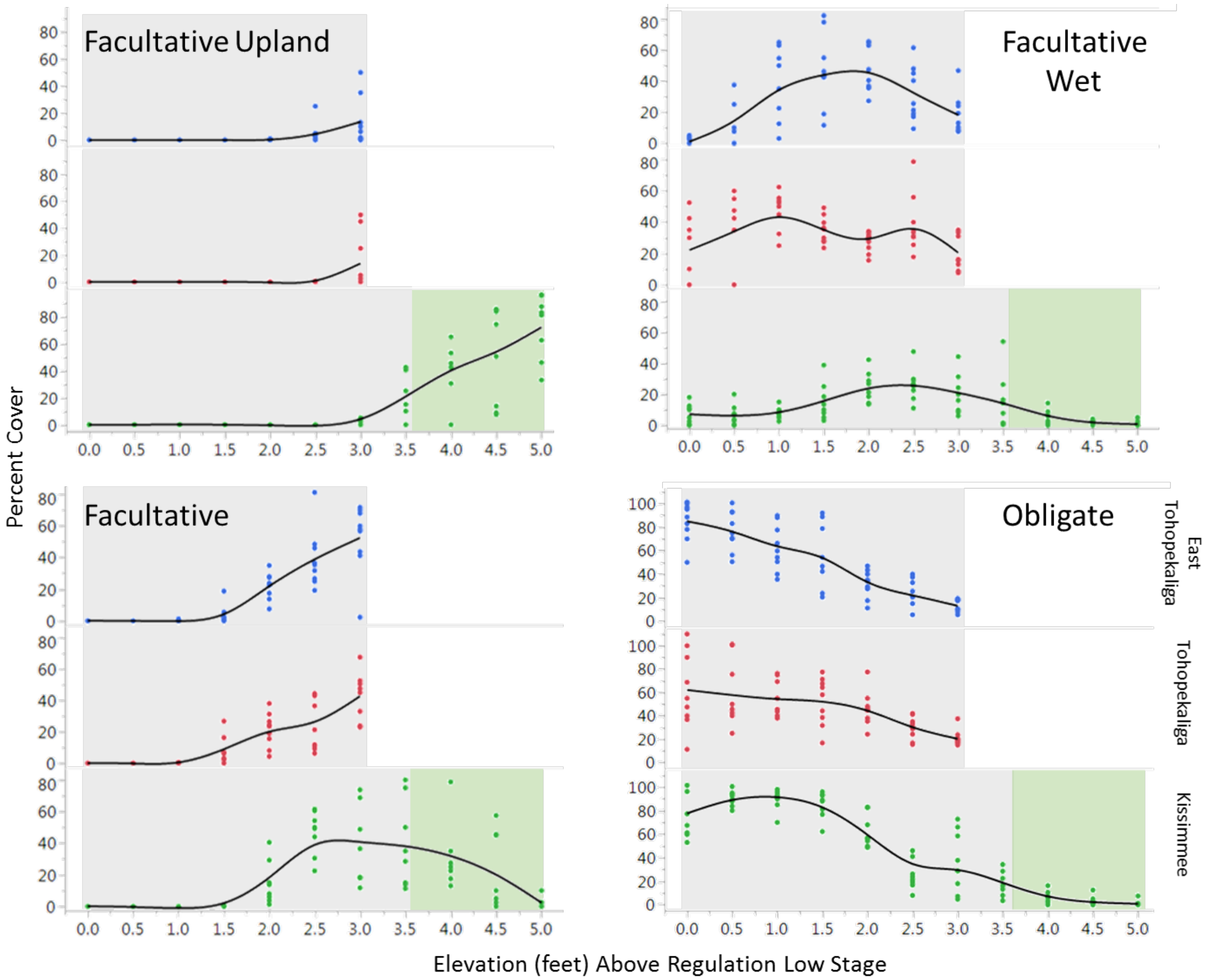


Figure 9-41. Abundance of species grouped by wetland indicator status along elevation gradients on each lake during annual samples from 2015-2017. Gray boxes represent the elevations of the current regulation schedule, and green represents the future regulation expansion on Lake Kissimmee upon completion of Kissimmee River Restoration. Indicator status, from dry to wet, is Facultative Upland, Facultative, Facultative Wet, and Obligate.

FISH POPULATION MONITORING

The status of the fishery in the KCOL is monitored on a regular basis by the FWC via electrofishing and creel surveys. Electrofishing surveys use a standardized sampling protocol implemented in 2007, where random transects are sampled for 15 minutes each. These efforts provide an assessment of the size distribution and abundance of largemouth bass (*Micropterus salmoides*) populations. Electrofishing surveys occur in the spring every 2 to 3 years on the major lakes in the KCOL, with the most recent summaries tallied for spring 2017 on Lakes Cypress, Hatchineha, Kissimmee, Marian, and Tohopekaliga. Catch per unit effort (CPUE) is one metric used to assess the annual abundance of largemouth bass, though catch rates can vary some with density of vegetation, water clarity, inclement weather, or an abundance of small size classes. CPUE ranged from 15.3 bass/hour on Lake Marian to 39.0 bass/hour on Lake Cypress (**Table 9-11**).

The annual size distributions generally show a bimodal peak if the population is doing well, with a peak in subadults (< 25 cm) indicating good production of young and a second peak in larger size classes indicating good recruitment of young into the population (**Figure 9-42**). When there are few to no subadults found in a given year, there typically is a subsequent decline in larger size classes within 2 to 3 years after, and the opposite can be found as well. In 2017, Lake Tohopekaliga appears to have had a particularly high number of subadults while low contributions of subadults were observed on the other lakes, especially Kissimmee and Marian. However, higher numbers of fish in the larger size classes were sampled from lakes Cypress, Hatchineha, and Kissimmee. Lake Marian had a relatively low number of fish sampled with very few subadult fish, in contrast with spring 2015 sampling when this lake had the highest CPUE of all the lakes sampled (although the 2015 catch also had few fish < 20 cm) (Koebel et al. 2017).

Overall 2017 largemouth bass catch rates were low; past years have seen 30-40 or more fish per hour. On most lakes, low subadult populations seemed to account for most of the difference. The 2015 and 2016 sampling events yielded average to above-average results (presented in previous versions of this report). FWC reports that differences are likely due to differences in sampling effort, namely inexperienced staff. There were two new employees responsible for netting during electrofishing surveys in 2017; people who are inexperienced are likely to be less efficient at seeing and identifying smaller bass (small subadult bass can be confused with other small common fish). Although 2016-2017 was dry, lake levels were held near average throughout the sampling season and creel surveys and other population indices FWC measures did not indicate a low subadult population.

Table 9-11. Mean CPUE values as fish/hour for largemouth bass collected by electrofishing from random transects in spring 2017. Each transect was sampled for 15 minutes. SE values are denoted in parentheses.

Lake	2017 Total
Marian	15.3 (2.9)
Hatchineha	25.6 (2.7)
Kissimmee	27.8 (3.8)
Tohopekaliga	28.3 (3.2)
Cypress	39.0 (5.5)

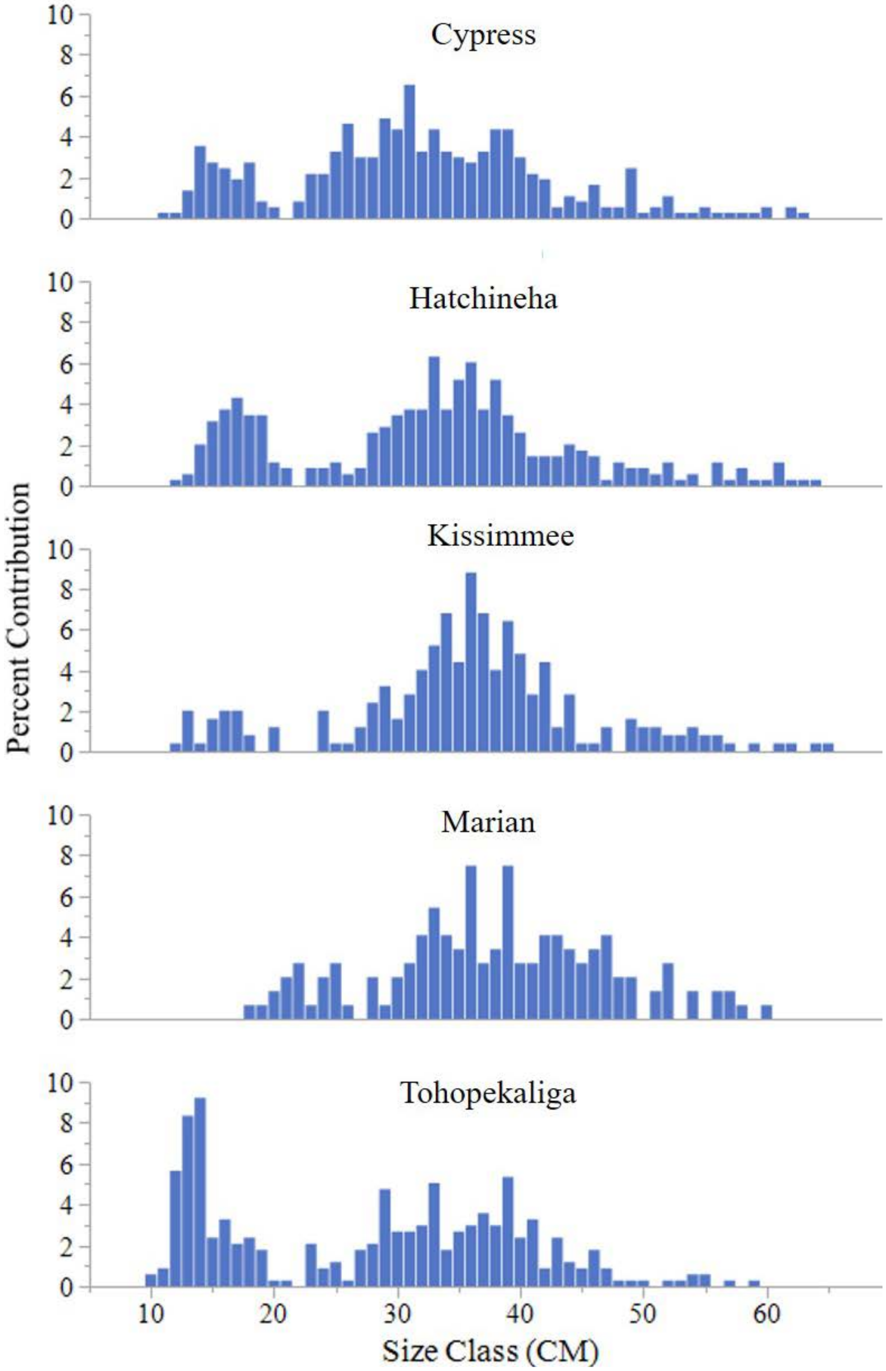


Figure 9-42. Length-frequency distribution (bars) for largemouth bass collected by electrofishing at lakes Cypress (n=368), Hatchineha (n=348), Kissimmee (n=249), Marian (n=147), and Tohopekaliga (n=337) during spring 2017. Fish lengths were placed into centimeter groups (e.g., 10 cm group = 10.00 through 10.99 cm TL).

SNAIL KITE POPULATION MONITORING

Statewide snail kite nesting effort, distribution, and population size are systematically monitored by the University of Florida on an annual basis (see Fletcher et al. [2018] for details). This monitoring effort covers most wetlands, statewide, in which snail kite breeding activity has been observed within the last decade or more. In the KCOL region, surveyed water bodies include East Lake Tohopekaliga and Lake Runnymede (grouped as East Lake Tohopekaliga); Lake Tohopekaliga; Lake Kissimmee; and lakes Jackson, Cypress, Hatchineha, and Marian (grouped as Other). Lake Okeechobee is also monitored for snail kites. The number of snail kites observed in each water body are counted and identified by their alpha-numeric leg bands, if possible. Survey crews also record nesting information; including the location, status (building, incubating, nestlings, failed, or successful), leg bands of parents (if possible), and other important characteristics. Following the first survey in January, each nest is revisited at about 3-week intervals until the nest is no longer active. Alpha-numeric leg bands are put on most nestlings when they are 24 days old for future identification and for estimating population size.

In 2017, survey crews located a total of 225 active nests (i.e., containing eggs or nestlings) throughout the snail kite's range in Central and South Florida. This represents a dramatic decrease in nesting effort from 2016 (778 active nests) and is the fewest active nests statewide since 2010 (190 active nests). Reduced nesting effort likely was a result of dry conditions early in the nesting season. Nesting effort showed a small increase after a large June rain event increased water levels in many wetlands. As has usually been the case since 2005, a large proportion of nests (53 total) were in the KCOL, accounting for 24% of the nesting effort in 2017. However, 53 active nests are the fewest in the KCOL region since 2006 (30 active nests). For the third year in a row, the KCOL did not have the most active or successful nests of any region; the Okeechobee and Other regions had more active and successful nests than the KCOL.

Lake Okeechobee had 88 active nests in 2017, 23 of which were successful. When Hurricane Irma made landfall in southwestern Florida, 47 snail kite nests were active in Lake Okeechobee. All 47 nests were found to have failed or been destroyed in a post-hurricane assessment. Five nests in Rotenberger Wildlife Management Area (RWMA) and one nest each in Mary A Mitigation Bank, Arthur R. Marshall Loxahatchee National Wildlife, and Water Conservation Area 3A also were destroyed by Hurricane Irma.

The Other region consists of any wetlands not encompassed by the KCOL, Okeechobee, Everglades Stormwater Treatment Areas (STAs), or Everglades regions. In 2017, the Other region was bolstered by a record amount of nesting effort in the RWMA. Prior to 2017, there had only been one snail kite nest recorded in the RWMA in 2013 near the border of STA-5. A wildfire burned most of the RWMA in May 2017 and higher than normal water levels following an extreme rain event occurred in June 2017. A handful of snail kite nests appeared in the RWMA in August but were destroyed by Hurricane Irma. Snail kites immediately built new nests and continued to nest in the RWMA through December. In total, there were 35 snail kite nests discovered in the RWMA in 2017, 18 of which were successful (fledged at least one young).

Within the KCOL, there were 31 nests located on Lake Tohopekaliga in 2017, 14% of the statewide nesting effort. Lake Kissimmee had 15 nests (7% of the statewide nesting effort) and East Lake Tohopekaliga had 7 nests (3% of the statewide nesting effort). There was no nesting documented on any other KCOL water body (**Figure 9-43C**). Of the 53 nests in the KCOL, 18 nests (34%) were observed to be successful (**Figure 9-43D**).

In summary, the KCOL region had a below-average year in terms of nesting effort and successful nests. Dry conditions during the nesting season were a probable cause of reduced nesting effort in the KCOL and the rest of the snail kite range. There was a late season surge in nesting once the wet season began in early June. This included 12 of Lake Tohopekaliga's 32 nests that were established in June and July. Mary A Mitigation Bank, Lake Okeechobee, and the RWMA had increased nesting in June or later. Unfortunately, Hurricane Irma put an end to many of these late nesting attempts. However, nesting continued through the end of the year in the RWMA.

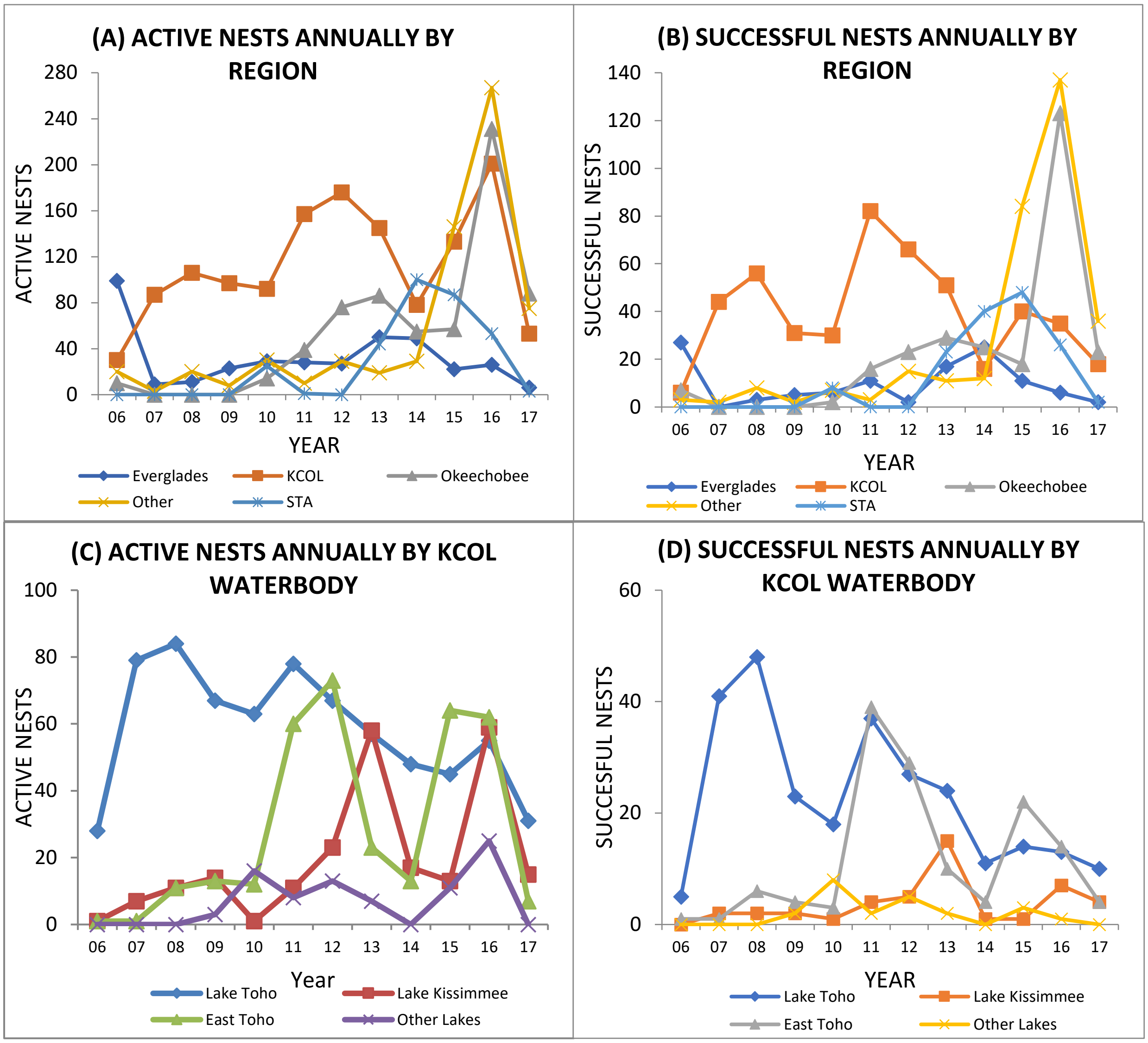


Figure 9-43. (A) Active snail kite nests for each region from 2006 to 2017 and (B) the total number successful. (C) Active snail kite nests for each major water body in the UKCL region, and (D) the total number successful from 2006 to 2017.

ALLIGATOR POPULATION MONITORING

The FWC conducts American alligator (*Alligator mississippiensis*) monitoring studies in many public water bodies throughout the state to obtain relative abundance of their populations (Hutton and Woolhouse 1989). Alligator activities vary seasonally (Lutterschmidt and Wasko 2006), so night light surveys are conducted from May through mid-June (spring surveys) and July through mid-August (summer surveys), and are analyzed separately. Survey routes are standardized and follow the perimeter of a lake along the open water-shoreline/marsh interface (Woodward and Marion 1978), or middle/centerline of a river/canal section, depending on width. Spotlights (200,000 candlepower) are used to locate alligator eye reflections and sizes are estimated to the nearest 1 ft, if possible. When the exact size cannot be determined, broader size categories (0–2 ft, 2–4 ft, 4–6 ft, ≥4 ft, ≥6 ft, and ≥9 ft) are used, or they are recorded as unknown size.

For trend analysis by year, counts are summed in each size category. Average date, water level, and water temperature within replicates are determined for each year. FWC uses Turnbull's (1976) approach for interval-censored data via the “%ice” SAS macro (So et al. 2010) to allocate counts into size categories. A modified version of this macro is used to produce an overall probability distribution function, describing the estimated proportions of unit-interval lengths for each replicate-unit-year sample. The probability distribution function is summed for specified portions of the alligator size range to produce the cumulative distribution function for each replicate-unit-year. Standard errors and 95% confidence intervals for cumulative distribution function are determined via the macro as well, and these are multiplied by the total number of all alligators counted for each replicate-unit-year sample to estimate the total count, its SE, and confidence limits.

FWC models year trends in the natural logarithms of the estimated counts using the generalized additive modeling package of the R statistical environment (Hastie 2009). Akaike's information criterion is used to select the best of six models from some combination of year and water level as predictors, modeled as either linear or spline (piecewise) regressions with four knots, or separations (de Boor 2001). The predictors in the six models are (1) linear year effect; (2) four-knot spline for year; (3) linear year and linear water level; (4) linear year and four-knot spline for water level; (5) linear water level and four-knot spline for year; (6) four-knot spline for year and four-knot spline for water level. A fixed detectability coefficient of 0.14 is applied to survey counts to generate population estimates from the generalized additive modeling analyses (Woodward et al. 1996).

Lake Kissimmee

Total alligator population estimates on Lake Kissimmee have continued to stay strong in recent years. The 2017 estimated population was 13,012 alligators, which is an increase of approximately 182% since population monitoring began in 1991 (**Figure 9-44a**). The estimated number of juvenile (1–4 ft) alligators was 6,751 individuals, which is a 315% increase over the 1991 estimated population. The adult (6 ft and larger) portion of the alligator population also increased and was estimated at 3,699 individuals, a 57% increase since 1991.

Lake Tohopekaliga

Total alligator population estimates on Lake Tohopekaliga have continued to stay strong. The 2017 estimated population was 7,826 alligators, an approximate increase of 263% since population monitoring began in 1994 (**Figure 9-44b**). The estimated number of juvenile (1–4 ft) alligators was 4,637 individuals, a 168% increase over the 1994 estimated population. The adult (6 ft and larger) portion of the alligator population also increased and was estimated at 1,372 individuals, an 86% increase over the 1994 estimated population.

East Lake Tohopekaliga

Total alligator population estimates on East Lake Tohopekaliga have remained relatively stable. The 2017 estimated population was 111 alligators, an increase of approximately 13% since population monitoring began in 2003. The estimated number of juvenile (1–4 ft) alligators was 26 individuals, a 13% decline from the 2003 estimated population. The adult (6 ft and larger) portion of the alligator population was 38 individuals, a 27% decrease from the 2003 estimated population.

Lake Hatchineha

Total alligator population estimates on Lake Hatchineha have remained strong. The 2017 estimated population was 3,444 alligators, an increase of approximately 185% since population monitoring began in 1988 (**Figure 9-44c**). The estimated number of juvenile (1–4 ft) alligators was 1,868 individuals, a 198% increase since 1988. The adult (6 ft and larger) portion of the alligator population also increased and was estimated at 1,013 individuals, a 149% increase over the 1988 estimated population.

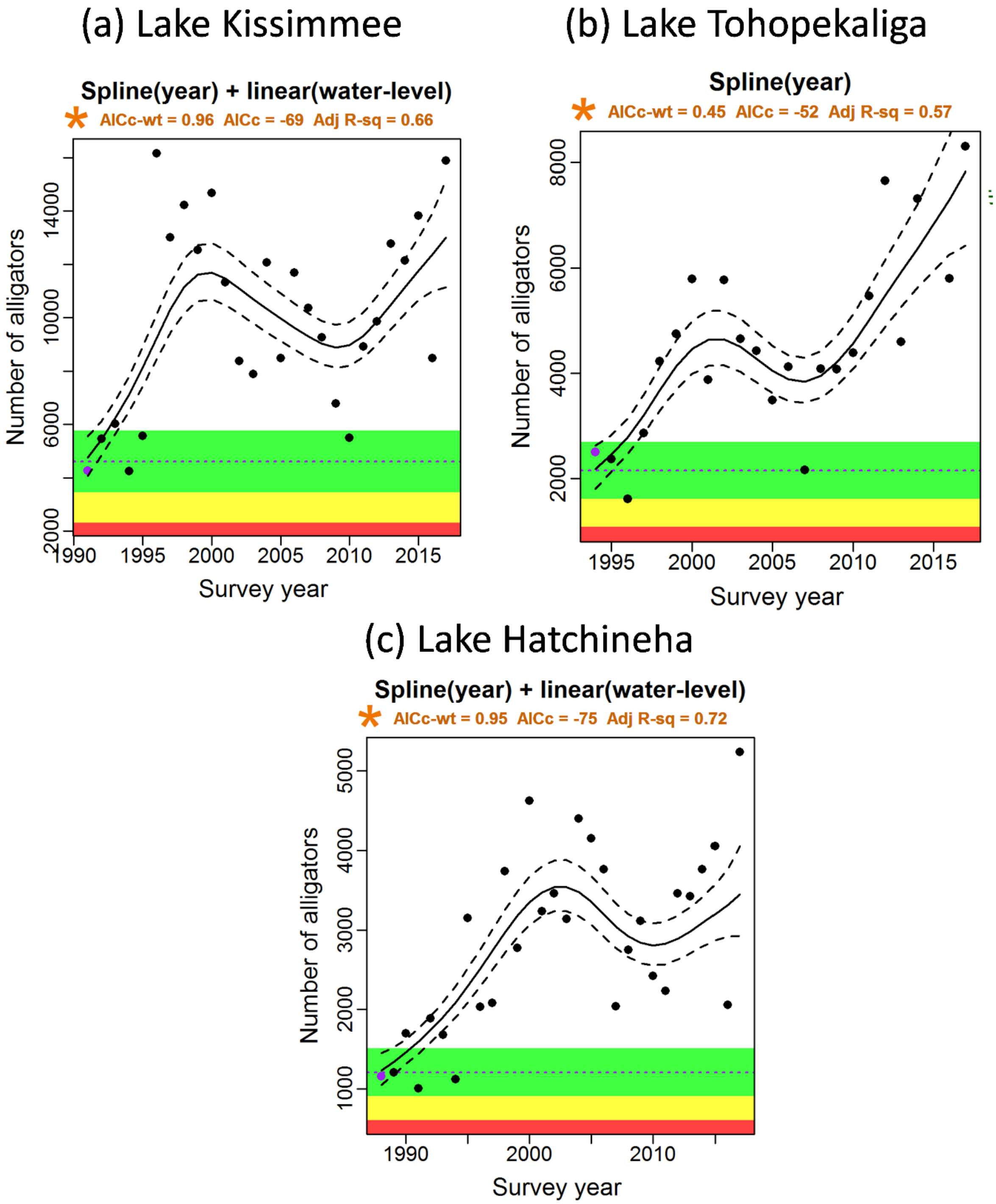
Cypress Lake

The 2017 estimated population on Cypress Lake was 760 alligators, a 22% decrease since population monitoring began in 2000. The estimated number of juvenile (1–4 ft) alligators was 135 individuals, while the estimated number of adult alligators was 439 individuals. Those estimates represent a 44% decline and a 1% increase, respectively, from the 2000 estimated population.

KCOL Alligator Populations Summary

Alligator populations on the three largest lakes within the KCOL (Kissimmee, Tohopekaliga, and Hatchineha) have shown increases in juvenile, adult, and total populations over the period for which monitoring surveys have been conducted. Increases in the number of juveniles could be an indication of sufficient nesting habitat, favorable nesting conditions, high hatching success, and sufficient habitat for hatchlings and juveniles. Likewise, increases in the number of adults possibly are due to high survival of juveniles and subsequently high recruitment of younger alligators into the adult size classes.

Trend analyses for East Lake Tohopekaliga and Cypress Lake are more mixed, with some indications of declines. The decline of adults on East Lake Tohopekaliga might reflect the harvest from recreational and nuisance trappers. Regardless of the reason, the estimated population is within the acceptable adult population limits for continued recreational harvests. The decline noted for the juveniles in East Lake Tohopekaliga is small enough to be considered a result of the variation in survey count data. The cause of the decline of juveniles on Cypress Lake is unclear but might reflect changes in the available habitat for smaller alligators. The removal of dense emergent vegetation and hydrilla can reduce the amount of available cover and foraging area for juvenile alligators. Allowing a buildup in selected areas around the lake could promote an increase in the number of juvenile alligators using the lake.



(a) Lake Kissimmee

(b) Lake Tohopekaliga

(c) Lake Hatchineha

Figure 9-44. Alligator population trends on (a) Lake Kissimmee, (b) Lake Tohopekaliga, and (c) Lake Hatchineha, based on night light surveys conducted between 1988 and 2017. Green-shaded area represents ±25% of the population management target; yellow-shaded area represents 25–50% of the target; and the red-shaded area represents ≤ 50% of the target. Dashed lines represent 70% confidence intervals around the solid trend line. Note that both the x- and y-axes scales vary between figures.

LITERATURE CITED

Abtew, W., R.S. Huebner and S. Sunderland. 2002. *The 2000–2001 Drought in South Florida*. South Florida Water Management District, West Palm Beach, FL.

Anderson, D.H. and J.R. Chamberlain. 2005. Expectation 3: Stage Hydrograph Characteristics. In D.H. Anderson, S.G. Bousquin, G.W. Williams and D.J. Colangelo (eds.), *Kissimmee River Restoration Studies, Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*, Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Anderson, D.H. 2014. Interim hydrologic responses to Phase I of the Kissimmee River Restoration Project, Florida. *Restoration Ecology* 22(3):353-366.

Anderson, D.H., S.G. Bousquin, G.W. Williams and D.J. Colangelo (eds.). 2005. *Kissimmee River Restoration Studi*es, *Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*. Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL. Available online at https://www.sfwmd.gov/document/kissimmee-river-restoration-studies-volume-ii-defining-success-expectations-restoration.

Baker, J.M., J.P. Hartley and B. Dicks. 1987. Planning Biological Surveys. Pages 1–26 in: J.M. Baker and W.J. Wolff (eds.), *Biological Surveys of Estuaries and Coasts*, Cambridge University Press, Cambridge, United Kingdom.

Bellrose, F.C. 1980. *Ducks, Geese, and Swans of North America, Third Edition*. Stackpole Books, Harrisburg, PA.

Bousquin, S.G. and J. Colee. 2014. Interim responses of littoral river channel vegetation to reestablished flow after Phase I of the Kissimmee River Restoration Project. *Restoration Ecology* 22(3):388-396.

Bousquin, S.G., D.H. Anderson, G.W. Williams and D.J. Colangelo (eds.). 2005. *Kissimmee River Restoration Studies, Volume I – Establishing a Baseline: Pre-restoration Studies of the Channelized Kissimmee River*. Technical Publication ERA 432, South Florida Water Management District, West Palm Beach, FL.

Bousquin, S.G., D.H. Anderson, D.J. Colangelo, J.L. Glenn III, J. Koebel and G.E. Williams. 2007. Phase I of the Kissimmee River Restoration Project: Initial river channel responses. In: K.C. Kabbes (ed.), *Restoring Our Natural Habitat: Proceedings of the 2007 World Environmental & Water Resource Congress*, American Society of Civil Engineers, Tampa, FL.

Bousquin, S.G., D.H. Anderson, D.J. Colangelo, B.L. Jones, M.D. Cheek and L. Spencer. 2008. Chapter 11: Kissimmee Basin. In: *2008 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Bousquin, S.G., D.H. Anderson, M.D. Cheek D.J. Colangelo, L. Dirk, J.L. Glenn, B.L. Jones, J.W. Koebel Jr., J.A. Mossa and J. Valdes. 2009. Chapter 11: Kissimmee Basin. In: *2009 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Carnal, L. 2005a. Expectation 12: Areal Coverage of Floodplain Wetlands. D.H. Anderson, S.G. Bousquin, G.W. Williams and D.J. Colangelo, eds. pp. 12-1 through 12-4. In *Kissimmee River Restoration Studies Volume II – Defining Success: Expectations for Restoration of the Kissimmee River.* South Florida Water Management District, West Palm Beach, FL. Technical Publication ERA 433. Available online at: http://my.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/krr_volii_expectations.pdf.

Carnal, L. 2005b. Expectation 13: Areal Coverage of Broadleaf Marsh. D.H. Anderson, S.G. Bousquin, G.W. Williams and D.J. Colangelo, eds. pp. 13-1 through 13-4. In *Kissimmee River Restoration Studies Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*. South Florida Water Management District, West Palm Beach, FL. Technical Publication ERA 433. Available online at: http://my.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/krr_volii_expectations.pdf

Carnal, L. 2005c. Expectation 14: Areal Coverage of Wet Prairie. D.H. Anderson, S.G. Bousquin, G.W. Williams and D.J. Colangelo, eds. pp. 14-1 through 14-4. In *Kissimmee River Restoration Studies Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*. South Florida Water Management District, West Palm Beach, FL. Technical Publication ERA 433. Available online at: http://my.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/krr_volii_expectations.pdf

Chamberlain, E.B. 1960. *Florida Waterfowl Populations, Habitats, and Management*. Technical Bulletin 7, Florida Game and Fresh Water Fish Commission, Tallahassee, FL.

Cheek, M.D., G.E. Williams, S.G. Bousquin, J. Colee and S.L. Melvin. 2014. Interim response of wading birds (Pelecaniformes and Ciconiiformes) and waterfowl (Anseriformes) to the Kissimmee River Restoration Project, Florida, U.S.A. *Restoration Ecology* 22(3):426-434.

Cheek, M.D., D.H. Anderson, D.J. Colangelo, S.G. Bousquin, B.L. Jones, L. Spencer, R.T. James, J. Zhang and C. Carlson. 2015. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2015 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Chen, H., S.G. Bousquin and D.H. Anderson. 2016. Dissolved Oxygen Dynamics in the Post-Phase I Kissimmee River Channel and Implications for Discharge Management. Poster presented at the 2016 National Conference on Ecological Restoration), Fort Lauderdale, FL, April 18–22, 2016.

Chen, H., S.G. Bousquin, and D.H. Anderson. 2018. Dissolved oxygen sag events in the Phase I of the Kissimmee River Restoration Project. Presented at the 12th International Symposium on Biogeochemistry of Wetlands, Coral Springs, FL April 23-26, 2018.

Colangelo, D.J. 2007. Response of river metabolism to restoration of flow in the Kissimmee River, Florida, U.S.A. *Freshwater Biology* 52:459-470.

Colangelo, D.J. and B. Jones. 2005. Expectation 8: Dissolved Oxygen Concentrations in the River Channel. Pages 8-1 through 8-6 in: D.H. Anderson, S.G. Bousquin, G.W. Williams and D.J. Colangelo (eds.) *Kissimmee River Restoration Studies, Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*, Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Daubenmire, R. 1959. A canopy-coverage method of vegetation analysis. *Northwest Science* 33:43-64.

de Boor, C. 2001. *A Practical Guide to Splines* (Revised Edition). Springer-Verlag, NY.

Department of the Army and SFWMD. 1994. *Project Cooperation Agreement between the Department of the Army and South Florida Water Management District for Construction of the Kissimmee River, Florida, Project*. United States Department of the Army, Washington, DC, and South Florida Water Management District, West Palm Beach, FL.

FGFWFC. 1957. Appendix B: Waterfowl Ecological Studies. In: *Recommended Program for Kissimmee River Basin*, Florida Game and Fresh Water Fish Commission, Tallahassee, FL.

Florida Game and Fresh Water Fish Commission. 1991. Lake Okeechobee-Kissimmee River-Everglades resource evaluation project. Federal Wallop-Breaux completion report. (F-52-5). Tallahassee, Florida.

Fletcher, R., E. Robertson, B. Jeffrey, C. Poli, and S. Dudek. 2018. *Snail Kite Demography 2018 Report on the 2017 Breeding Season*. Prepared by University of Florida, Gainesville, FL, and submitted to United States Army Corps of Engineers, Jacksonville, FL, and Florida Fish and Wildlife Conservation Commission, Tallahassee, FL.

Frahn, K., S. Gehrig, J. Nicol and K. Marsland. 2014. *Lower Lakes Vegetation Condition Monitoring – 2013/2014*. Report Number 795, South Australian Research and Development Institute, Adelaide, South Australia.

Frederick, P.C. and M.W. Collopy. 1989. Nesting success of five ciconiiform species in relation to water conditions in the Florida Everglades. *The Auk* 106:625-634.

Frederick, P., T. Towles, R. Sawicki and T. Bancroft. 1996. Comparison of aerial and ground techniques for discovery and census of wading bird (C*iconiiformes*) nesting colonies. *The Condor* 98:837-841.

Furse, J.B., L.J. Davis and L.A. Bull. 1996. Habitat use and movements in largemouth bass associated with changes in dissolved oxygen and hydrology in Kissimmee River, Florida. *Proceedings of the Annual Conference Southeast Association of Fish and Wildlife Agencies* 50:12-25.

Gawlik, D. 2002. The effects of prey availability on the numerical response of wading birds. *Ecological Monographs* 72(3):329-346.

Glenn, J.L., and D.A. Arrington. 2005. Chapter 13: Status of Fish Assemblages of the Kissimmee River Prior to Restoration. Pages 13.11–13.58 in: S.G. Bousquin, D.H. Anderson, G.E. Williams and D.J. Colangelo (eds.), *Kissimmee River Restoration Studies, Volume I – Establishing A Baseline: Pre-restoration Studies of the Channelized Kissimmee River*. South Florida Water Management District, West Palm Beach, FL.

Harris, S.C., T.H. Martin and K.W. Cummins. 1995. A model for aquatic invertebrate response to Kissimmee River restoration. *Restoration Ecology* 3(3):181-194.

Hastie, T. 2009. *R Package Version 1.01*. Palo Alto, CA.

Hauer, F.R. and G.A. Lamberti. 2007. *Methods in Stream Ecology, 2nd Edition*. Academic Press, San Diego, CA.

Hutton, J.M. and M.E.J. Woolhouse. 1989. Mark-recapture to assess factors affecting the proportion of a Nile crocodile population seen during spotlight counts at Ngezi, Zimbabwe, and the use of spotlight counts to monitor crocodile abundance. *Journal of Applied Ecology* 26:381-395.

Jones, B.L., B. Anderson, D.H. Anderson, S.G. Bousquin, C. Carlson, M.D. Cheek, D.J. Colangelo and L. Spencer. 2010. Chapter 11: Kissimmee Basin. In: *2010 South Florida Environmental Report – Volume I,* South Florida Water Management District, West Palm Beach, FL.

Jones, B.L., S.G. Bousquin, D.H. Anderson, D.J. Colangelo, L. Spencer, J.W. Koebel Jr., M.D. Cheek, J. Valdés, B. Anderson and C. Carlson. 2011. Chapter 11: Kissimmee Basin. In: *2011 South Florida Environmental Report – Volume I,* South Florida Water Management District, West Palm Beach, FL.

Jones, B.L., D.H. Anderson, S.G. Bousquin, C. Carlson, M.D. Cheek, D.J. Colangelo and L. Dirk. 2012. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2012 South Florida Environmental Report – Volume I,* South Florida Water Management District, West Palm Beach, FL.

Jones, B.L., D.H. Anderson, S.G. Bousquin, C. Carlson, M.D. Cheek, D.J. Colangelo and R.T. James. 2013. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2013 South Florida Environmental Report – Volume I,* South Florida Water Management District, West Palm Beach, FL.

Jones, B.L., D.J. Colangelo, D.H. Anderson, S.G. Bousquin, M.D. Cheek, C. Carlson and R.T. James. 2014. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2014 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Junk, W.J., P.B. Bayley and R.E. Sparks. 1989. The flood pulse concept in river floodplain systems. Pages 110-127 in: D.P. Dodge (ed), *Proceedings of the International Large River Symposium*, Honey Harbour Ontario, Canada, September 14–21, 1986, Canadian Special Publication of Fisheries and Aquatic Sciences 106, Ontario Ministry of Natural Resources, Toronto, Ontario, Canada.

Karr, J.R. and D.R. Dudley. 1981. Ecological perspectives on water quality goals. *Environmental Management* 5:55-68.

Koebel, J.W. 2005. Expectation 17: Aquatic Invertebrate Community Structure in Broadleaf Marshes. Pages 17.11–17.13 in: D.H. Anderson, S.G. Bousquin, G.E. Williams and D.J. Colangelo (eds). *Kissimmee River Restoration Studies, Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*. Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Koebel, J.W. and S. Bousquin. 2014. The Kissimmee River Restoration Project and Evaluation Program, Florida, U.S.A. *Restoration Ecology* 22(3):345-352.

Koebel, J.W., S.G. Bousquin, D.H. Anderson, Z. Welch, M.D. Cheek, H. Chen, R.T. James, J. Zhang, B.C. Anderson, R. Baird, T. Beck, A. Brunell, D.J. Colangelo, T. Coughlin, K. Lawrence and C. Mallison. 2016. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2016 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Koebel, J.W., S.G. Bousquin, D.A. Anderson, Z. Welch, M.D. Cheek, H. Chen, B.C. Anderson, R. Baird, T. Beck, A. Brunell, T. Coughlin and C. Mallison. 2017. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2017 South Florida Environmental Report – Volume I,* South Florida Water Management District, West Palm Beach, FL.

Koebel, J.W., S.G. Bousquin, D.A. Anderson, M.D. Cheek, Zack Welch, H. Chen, B.C. Anderson, L. Spencer, T. Beck, T. Coughlin and C. Mallison. 2018. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2016 South Florida Environmental Report – Volume I,* South Florida Water Management District, West Palm Beach, FL.

Kushlan, J.A. 1990. Freshwater Marshes. Pages 324–363 in: R.L. Myers and J.J. Ewel (eds), *Ecosystems of Florida*, University of Central Florida Press, Orlando, FL.

Lee, D. S., C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer, Jr. 1980. Atlas of North America freshwater fishes. North Carolina State Museum of Natural History, Raleigh, North Carolina.

Lichvar, R.W., N.C. Melvin, M.L. Butterwick, and W.N. Kirchner. 2012. National Wetland Plant List Indicator Rating Definitions. ERDC/CRREL TR-12-1. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH.

Lutterschmidt, W.I. and D.K. Wasko. 2006. Seasonal activity, relative abundance, and size-class structure of the American alligator (*Alligator mississippiensis*) in a highly disturbed inland lake. *The Southwestern Naturalist* 51:346-351.

McCune, B. and J.B. Grace. 2002. *Analysis of Ecological Communities.* MjM Software Design, Gleneden Beach, OR.

National Audubon Society. 1936–1959. Audubon Warden Field Reports. Everglades National Park, South Florida Research Center, Homestead, FL.

NRC. 1992. *Restoration of Aquatic Ecosystems*. National Research Council, National Academy Press, Washington, DC.

Obeysekera, J. and K. Loftin. 1990. Hydrology of the Kissimmee River Basin – Influence of Man-made and Natural Changes. Pages 211–222 in: M.K. Loftin, L.A. Toth and J.T.B. Obeysekera (eds.), *Proceedings of the Kissimmee River Restoration Symposium,* South Florida Water Management District, West Palm Beach, FL.

Osenberg, C.W., B.M. Bolker, J-S. S. White, C.M. St. Mary and J.S. Shima. 2006. Statistical Issues and Study Design in Ecological Restoration: Lessons Learned from Marine Reserves. Pages 280–302 in: D.A. Falk, M.A. Palmer and J.B. Zedler (eds.), *Foundations of Restoration Ecology*, Island Press, Washington, DC.

Parker, G.G., G.E. Ferguson and S.K. Love. 1955. *Water Resources of Southeastern Florida*. Water Supply Paper 1255, United States Geological Survey, United States Government Printing Office, Washington, DC.

Pierce, G. J., A. B. Amerson, and L. R. Becker. 1982. Final report: pre-1960 floodplain vegetation of the lower Kissimmee River valley, Florida. Biological Services Report 82-3. U. S. Army Corps of Engineers, Jacksonville, Florida, USA.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks and J.C. Stromberg. 1997. The natural flow regime. *Bioscienc*e 47:769-784.

Rood, S.B., G.M. Samuelson, J.H. Braatne, C.R. Gourley, F.M.R. Hughes and J.M. Mahoney. 2005. Managing river flows to restore floodplain forests. *Frontiers in Ecology and the Environment* 3:193-201.

SAS Institute, Inc. 2016. *The TTEST procedure,* JMP 13.1.0. SAS Institute, Inc., Cary, NC.

SFWDAT. 2018. *South Florida Water Depth Assessment Tool*. South Florida Water Management District, West Palm Beach, FL.

SFWMD, FWC, FDEP, FDACS, USACE, USFWS, and Osceola County. 2011. *Kissimmee Chain of Lakes Long-Term Management Plan*. South Florida Water Management District, West Palm Beach, FL; Florida Fish and Wildlife Conservation Commission, Vero Beach, FL; Florida Department of Environmental Protection, Tallahassee, FL; Florida Department of Agriculture and Consumer Services, Tallahassee, FL; United States Army Corps of Engineer, Jacksonville, FL; United States Fish and Wildlife Service, Vero Beach, FL; and Osceola County, Kissimmee, FL.

Smith, J.P., J.R. Richardson and M.W. Collopy. 1995. Foraging habitat selection among wading birds (Ciconiiformes) at Lake Okeechobee, Florida, in relation to hydrology and vegetative cover. *Archiv für Hydrobiologie Special Issues Advances in Limnology* 45:247-285.

So, Y., G. Johnston and S.H. Kim. 2010. *Analyzing Interval-censored Survival Data with SAS Software*. SAS Institute Inc., Cary, NC.

Spencer, L. and S. Bousquin. 2014. Interim responses of floodplain wetland vegetation to Phase I of the Kissimmee River Restoration Project: Comparisons of vegetation maps from five periods in the river's history. *Restoration Ecology* 22(3):397-408.

Stewart-Oaten, A., J.R. Bence and C.W. Osenberg. 1992. Assessing effects of unreplicated perturbations: No simple solutions. *Ecology* 73(4):1396-1404.

Tichý, L. and M. Chytrý. 2006. Statistical determination of diagnostic species for site groups of unequal size. *Journal of Vegetation Science* 17:809-818.

Toth, L.A. 2010. Restoration response of relict broadleaf marshes to increased water depths. *Wetlands* 30:263-274.

Toth, L.A., S.L. Melvin, D.A. Arrington and J. Chamberlain. 1998. Hydrologic manipulations of the channelized Kissimmee River. *Bioscience* 48:757-764.

Toth, L.A., J.W. Koebel, Jr., A.G. Warne and J. Chamberlain. 2002. Implications of Reestablishing Prolonged Flood Pulse Characteristics of the Kissimmee River and Floodplain Ecosystem. Pages 191-221 in: B.A. Middleton (ed), *Flood Pulsing in Wetlands: Restoring the Natural Hydrological Balance*, John Wiley & Sons, Inc., New York, NY.

Trexler, J. C. 1995. Restoration of the Kissimmee River: a conceptual model of past and present fish communities and its consequences for evaluating restoration success. Restoration Ecology 3:195-210.

Turnbull, B.W. 1976. The empirical distribution function with arbitrarily grouped, censored and truncated data. *Journal of the Royal Statistical Society* Series B (Methodological):290-295.

USACE. 1991. *Final Integrated Feasibility Report and Environmental Impact Statement for the Restoration of the Kissimmee River, Florida*. United States Army Corps of Engineers, Jacksonville, FL.

USACE. 1996. *Central and Southern Florida Project, Kissimmee River Headwaters Revitalization Project: Integrated Project Modification Report and Supplement to the Final Environmental Impact Statement*. United States Army Corps of Engineers, Jacksonville, FL.

USFWS. 1991. *Fish and Wildlife Coordination Act Report: Kissimmee River Restoration Project*. United States Fish and Wildlife Service, Vero Beach, FL.

USFWS. 2017. Waterfowl population status, 2017. U.S. Department of the Interior, Washington, D.C. USA.

Warne, A.G., L.A. Toth and W.A. White. 2000. Drainage-basin-scale geomorphic analysis to determine reference conditions for ecological restoration – Kissimmee River, Florida. *Geological Society of America Bulletin* 112:884-899.

Weller, M.W. 1995. Use of two waterbird guilds as evaluation tools for the Kissimmee River restoration. *Restoration Ecology* 3:211-224.

Wetzel, R.G. 2001. *Limnology, 3rd Edition*. Academic Press, San Diego, CA.

White, C.L., P.C. Frederick, M.B. Main and J.A. Rogers, Jr. 2005. *Nesting Island Creation for Wading Birds*. Circular 1473, Wildlife Ecology and Conservation Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL. Available at http://edis.ifas.ufl.edu/uw223.

Williams, G.E. and S.L. Melvin. 2005a. Chapter 14: Studies of Bird Assemblages and Federally-listed Bird Species of the Channelized Kissimmee River, Florida. Pages 14-1 through 14-30 in: D.H. Anderson, S.G. Bousquin, G.W. Williams and D.J. Colangelo (eds.), *Kissimmee River Restoration Studies Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*, Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Williams, G.E. and S.L. Melvin. 2005b. Expectation 24: Density of Long-legged Wading Birds on the Floodplain. Pages 24-1 through 24-5 in: D.H. Anderson, S.G. Bousquin, G.W. Williams and D.J. Colangelo (eds.), *Kissimmee River Restoration Studies, Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*, Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Williams, G.E., B.D. Dugger and S.L. Melvin. 2005a. Expectation 25: Winter Abundance of Waterfowl on the Floodplain. Pages 25-1 through 25-5 in: D.H. Anderson, S.G. Bousquin, G.W. Williams and D.J. Colangelo (eds.), *Kissimmee River Restoration Studies, Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*, Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Williams, G.E., Jr., J.W. Koebel Jr., D.H. Anderson, S.G. Bousquin, D.J. Colangelo, J.L. Glenn, B.L. Jones, C. Carlson, L. Carnal and J. Jorge. 2005b. Chapter 11: Kissimmee River Restoration and Upper Basin Initiatives. In: *2005 South Florida Environmental Report – Volume I*, West Palm Beach, FL.

Williams, G.E., Jr., D.H. Anderson, S.G. Bousquin, C. Carlson, D.J. Colangelo, J.L. Glenn, B.L. Jones, J.W. Koebel Jr. and J. Jorge. 2006. Chapter 11: Kissimmee River Restoration and Upper Basin Initiatives. In: *2006 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Williams, G.E., D.H. Anderson, S.G. Bousquin, C. Carlson, D.J. Colangelo, J.L. Glenn, B.L. Jones, J.W. Koebel Jr. and J. Jorge. 2007. Chapter 11: Kissimmee River Restoration and Upper Basin Initiatives. In: *2007 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Winemiller, K.O., C.G. Montaña, D.L. Roelke, J.B. Cotner, J.V. Montoya, L. Sanchez, M.M. Castillo and C.A. Layman. 2014. Pulsing hydrology determines top-down control of basal resources in a tropical river-floodplain ecosystem. *Ecological Monographs* 84:621-635.

Woodward, A.R. and W.R. Marion. 1978. An evaluation of factors affecting night-light counts of alligators. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 32:291-302.

Woodward, A.R., K.G. Rice and S.B. Linda. 1996. Estimating sighting proportions of American alligators during night-light and aerial helicopter surveys. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 50:509-519.