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PHASE I OF THE KISSIMMEE RIVER RESTORATION PROJECT, FLORIDA, USA: IMPACTS OF CONSTRUCTION ON WATER QUALITY

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Abstract. Phase I of the Kissimmee River restoration project included backfilling of 12 km of canal and restoring flow through 24 km of continuous river channel. We quantified the effects of construction activities on four water quality parameters (turbidity, total phosphorus flow-weighted concentration, total phosphorus load and dissolved oxygen concentration). Data were collected at stations upstream and downstream of the construction and at four stations within the construction zone to determine if canal backfilling and construction of 2.4 km of new river channel would negatively impact local and downstream water quality. Turbidity levels at the downstream station were elevated for approximately 2 weeks during the one and a half year construction period, but never exceeded the Florida Department of Environmental Protection construction permit criteria. Turbidity levels at stations within the construction zone were high at certain times. Flow-weighted concentration of total phosphorus at the downstream station was slightly higher than the upstream station during construction, but low discharge limited downstream transport of phosphorus. Total phosphorus loads at the upstream and downstream stations were similar and loading to Lake Okeechobee was not significantly affected by construction. Mean water column dissolved oxygen concentrations at all sampling stations were similar during construction.

Keywords: construction impact, dissolved oxygen, ecological restoration, Kissimmee River, total phosphorus loads, turbidity, water quality

1. Introduction

The Kissimmee River, located in central Florida, U.S.A., once meandered 166 km within a 3–5 km wide floodplain, from Lake Kissimmee south to Lake Okeechobee (Koebel, 1995). In response to flooding caused by hurricanes during the late 1940s, Congress authorized the Central and Southern Florida Flood Control Project. Between 1962 and 1971, a 90-km long, 9-m deep, 100-m wide flood control canal (C-38) was dredged through the Kissimmee River valley, transforming the free-flowing river into a series of impounded reservoirs or "pools" (Pools A–E) separated by water control structures (S-65–S-65E) (Figure 1) (Koebel *et al.*, 1999). Channelization eliminated 12 000—14 000 ha of floodplain wetlands, degraded fish and wildlife habitat structure and water quality (Toth, 1993) and destroyed the ecological integrity of the system.

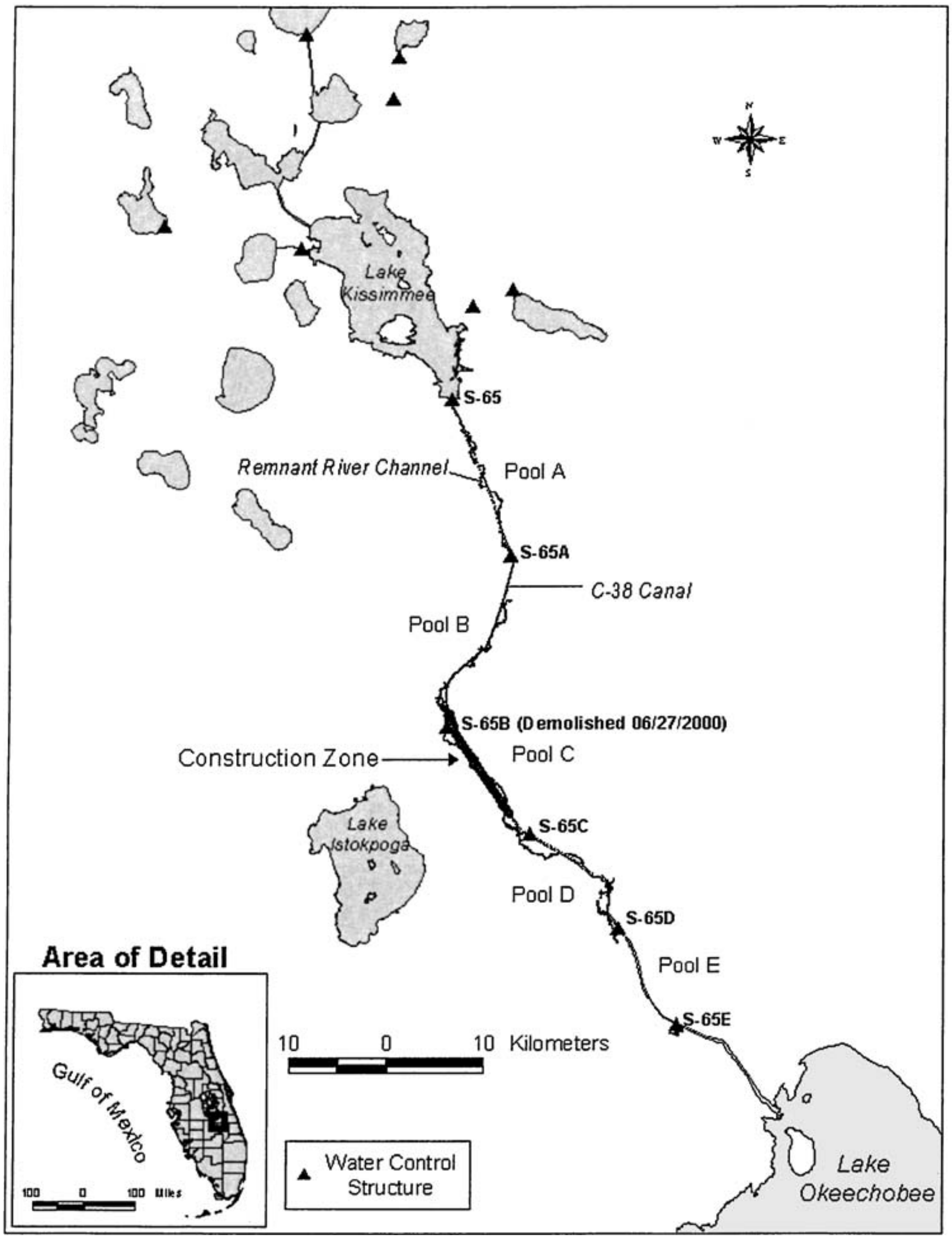

Figure 1. The channelized Kissimmee River and locations of water control structures in the upper and lower Kissimmee basins. Construction zone represents the area where canal backfilling, river channel re-carving and spoil degrading occurred between June 1999 and February 2001.

Prior to the completion of channelization, a grassroots movement to restore the Kissimmee River began to form. In 1976, the Florida Legislature passed the Kissimmee River Restoration Act in response to environmental concerns associated with channelization of the river (Koebel, 1995). In 1992, Congress authorized the Kissimmee River Restoration project after a series of feasibility studies showed that restoration of the ecosystem was possible.

Phase I of the Kissimmee River restoration project began in June 1999 and was completed in February 2001. This phase included moving 9.2 million cubic meters of dredged spoil to backfill 12 km of canal (C-38); removing one water control structure (S-65B); constructing two sections (2.4 km) of new river channel and re-establishing flow through 24 km of continuous river (Figures 1 and 2). This "full restoration" project (Cairns, 1991) seeks to restore the pre-channelization habitat structure and function (National Research Council, 1992; Toth *et al.*, 1995; Society for Ecological Restoration Science and Policy Working Group, 2002) and associated ecology of the river channel—floodplain ecosystem. The project is unique in that full restoration is rarely attempted or achieved (Brookes and Shields, 1996; Jungwirth *et al.*, 2002).

In 1994, a 330-m section of C-38 was backfilled as a precursor to Phase I of the restoration project. Water quality monitoring during this pilot project demonstrated that backfilling of C-38 could be accomplished without major impacts to downstream water quality and served as a model for the monitoring network developed for Phase I. During the pilot project, increases in turbidity and total suspended solids, as well as changes in dissolved oxygen (DO), were observed near the construction area. However, these effects were of short duration and had no apparent adverse impacts on fish and wildlife (Koebel *et al.*, 1999). Although water quality impacts from the pilot project were minor, monitoring of Phase I construction was necessary because it involved backfilling on a larger scale, occurred over a longer time period and included carving new river channel sections. The objectives of this study were to evaluate (1) the extent and duration of construction-generated turbidity, (2) changes in downstream total phosphorus (TP) flow-weighted concentration (FWC) and loading and (3) changes in local and downstream DO concentration.

Phosphorus is a concern because dredging and backfilling projects tend to cause increased suspended sediment (that could contain phosphorus) in the water column which can be transported downstream to other water bodies. The Kissimmee River is the largest tributary to Lake Okeechobee, which has become more eutrophic due to excessive phosphorus inputs from the lake's agricultural watershed (Federico *et al.*, 1981; Havens *et al.*, 1996). Legislation and regulation require stringent limits on phosphorus loads from the Kissimmee River and other lake tributaries (FDEP, 2001). Any additional loading caused by restoration construction would be included in tabulations of lake loading that monitor progress toward achieving the target load. Excessive turbidity from canal backfilling and dredging is aesthetically offensive and is potentially harmful to aquatic organisms. High turbidity can cause an increase in invertebrate drift due to decreased light in the water

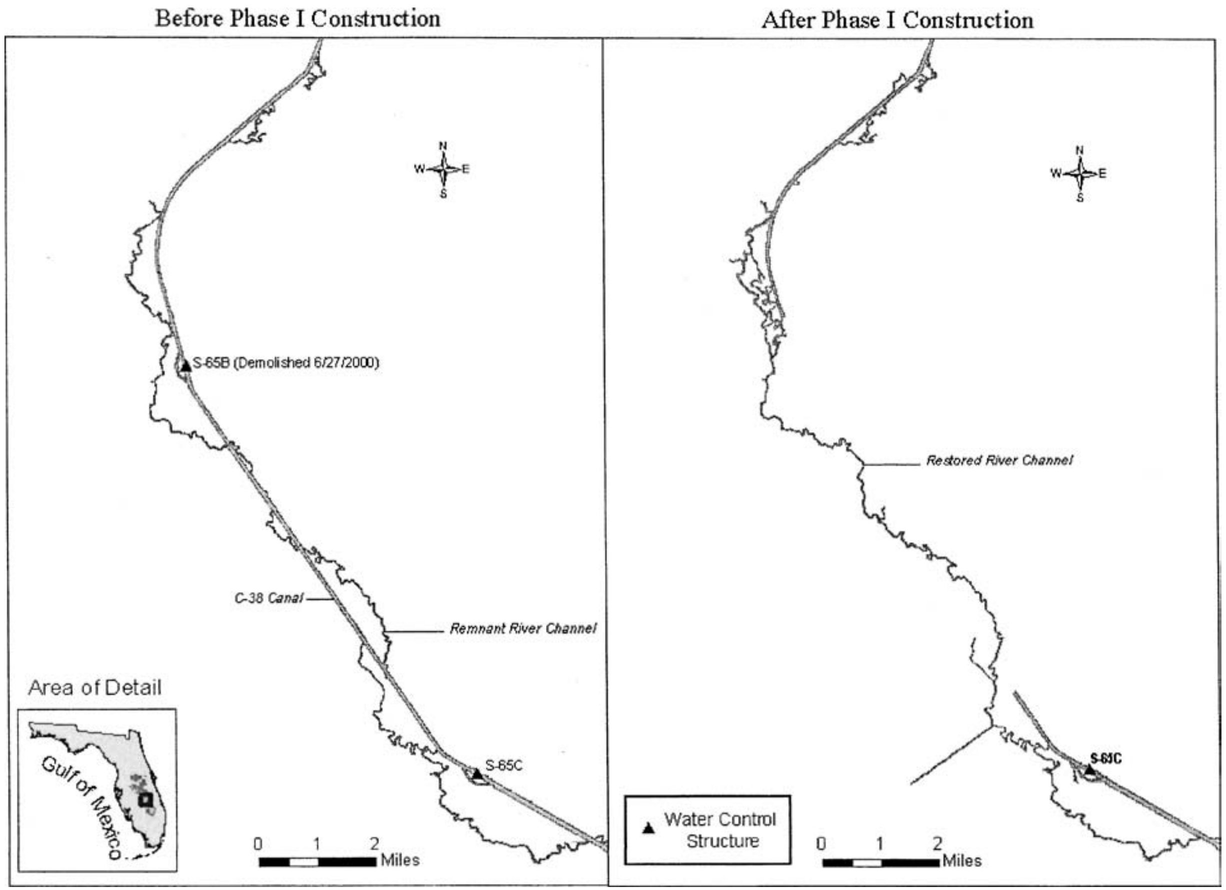

Figure 2. Pools B and C of the Kissimmee River and C-38, before and after Phase I of the restoration project.

column (Waters, 1995). Effects on fishes can include avoidance of highly turbid areas, reduced feeding and growth, respiratory impairment and reduced tolerance to disease and toxicants (Waters, 1995). High turbidity levels also could lower DO concentrations by shading the water column and inhibiting photosynthesis, or by increasing oxygen demand through disturbance of benthic mud and detritus. Monitoring changes in DO concentrations is an important part of the restoration project because low DO levels have stressed fish populations and caused degradation of biological communities within the channelized system (Toth *et al.*, 1990; Wullschleger *et al.*, 1990; Florida Game and Fresh Water Fish Commission, 1991; Toth, 1993; Furse *et al.*, 1996). Dissolved oxygen concentrations in remnant river channels of the channelized system, typically vary from <1–2 mg/L in the warm, wet season (June–November) and 2–4 mg/L in the cooler, dry season (December–May) (Colangelo and Jones, 2001).

2. Methods

2.1. CONSTRUCTION METHODS

Phase I construction began in June 1999 by building an earthen plug across C-38 (Initial Phase I crossing in Figure 3) approximately 3 km north of S-65C, forcing discharge to pass through MacArthur Run before re-entering C-38 further south. As construction progressed from south to north, backfilling was accomplished by isolating areas of active backfilling and highly turbid water from the rest of the canal–river system within "cells" along C-38. These cells were created by constructing earthen plugs across sections of C-38 and then backfilling the open-water areas between the plugs. Access roads were built between spoil piles and over segments of remnant river channel. In most cases, culverts were placed under access roads so that flow through reconnected river channels would not be impeded. As backfilling continued, each spoil pile was degraded to the elevation of surrounding floodplain and access roads and culverts between spoil piles were removed. Two new sections of river channel (Loftin Run and Strayer Run) were carved through the floodplain to replace historic river channels destroyed by the dredging of C-38 (Figure 3). In June 2000, water control structure S-65B was demolished and the surrounding area was graded to floodplain elevation, restoring full hydraulic connectivity between Pools B and C.

2.2. MONITORING STATIONS

To assess potential construction impacts on water quality, seven monitoring stations (Figure 3) were established before construction began in June 1999. Three stations were located in C-38. Station AMB was located upstream of the construction zone and provided data on ambient turbidity and DO. Water quality within the study area

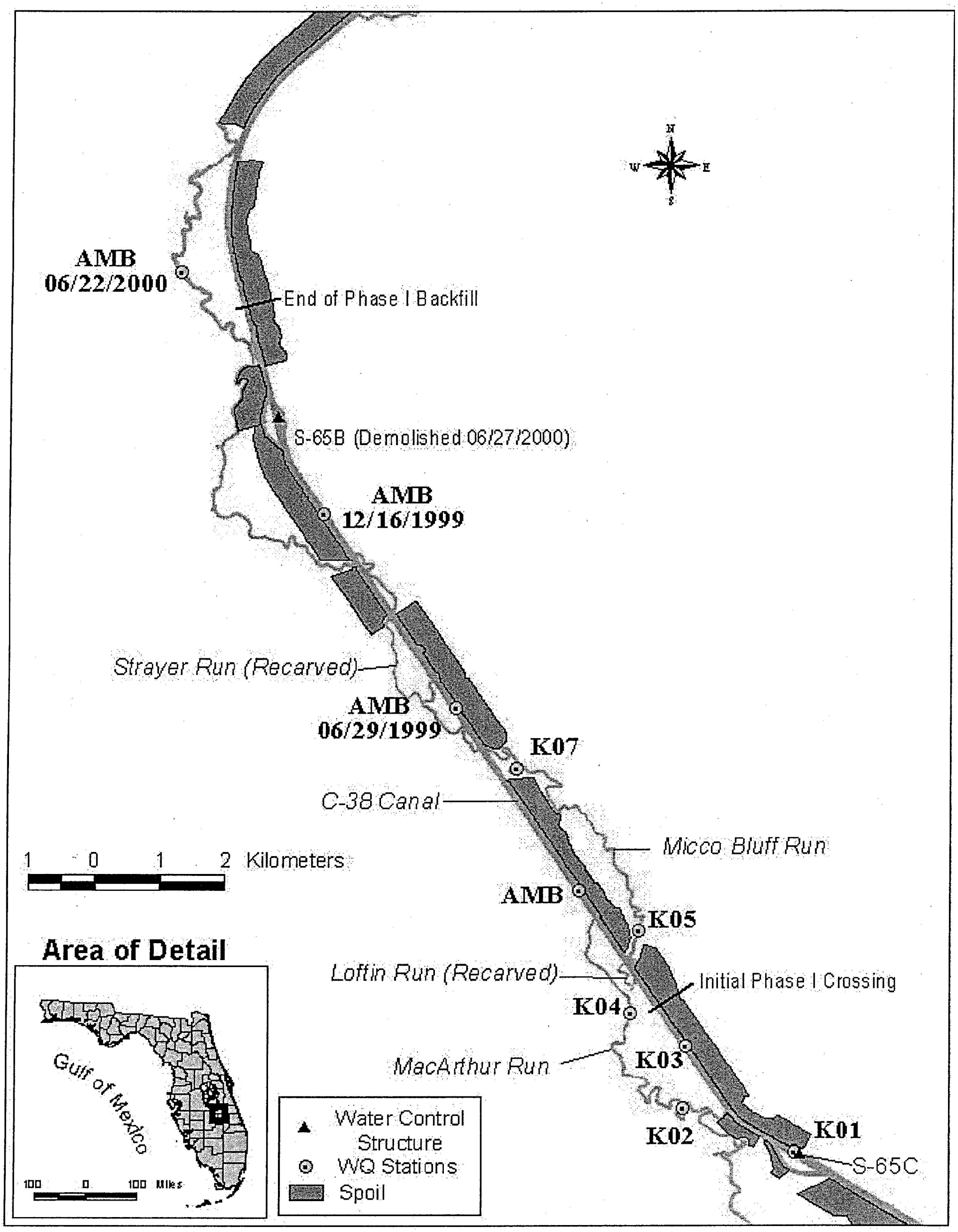

Figure 3. Location of water quality monitoring stations within the construction zone of Phase I of the Kissimmee River restoration project.

is generally homogenous, (Colangelo and Jones, 2001; Jones, 2002) and station AMB was representative of water entering the area of active construction. This station was used for determining how water quality changed as it passed through the construction zone. As backfilling proceeded northward, station AMB was relocated further north to avoid any influence from construction. Stations S-65C and K03 were established upstream of water control structure S-65C and 1-km downstream of the construction zone, respectively, and provided data on the downstream extent of water quality impacts. Four stations (K02, K04, K05 and K07) were located in MacArthur Run and Micco Bluff Run, the first two remnant river channels to receive flow. These stations provided data on construction impacts within the river channel.

Additionally, the Florida Department of Environmental Protection (FDEP) construction permit required turbidity samples to be taken daily at a station 500-m upstream of the northernmost limit of any visible turbidity plume caused by construction activity and upstream of S-65C. If turbidity at the downstream station exceeded turbidity at the upstream station + 29 NTU, construction had to cease. These data were collected by a contractor and used by the FDEP to evaluate permit compliance, but were not used for statistical analyses in this study.

Data from long-term water quality stations at water control structures S-65A, S-65C and S-65-E were used for baseline and post-construction analyses. Water samples were taken with a Van Dorn bottle within 0.5 m of the water surface on the upstream side of the water control structures. Samples were collected biweekly and analyzed for turbidity (Standard Method (SM) 2130B; American Public Health Association (APHA), 1985) and TP (SM 4500PF; APHA, 1985). Dissolved oxygen at 0.5 m was measured at the same time water samples were collected using a multiparameter water quality instrument.

Total phosphorus loads were calculated using these samples, except for samples collected when structures were closed (i.e., no flow through the pool). During most of the period of record, samples also were collected on the upstream side of each structure with automatic samplers, which collected water samples 10 times per day and combined them over 24-hour periods. Daily, composite samples were transported weekly to the lab for analysis. The data were averaged if two or more samples (grab or automated) were collected on a given day. Total phosphorus concentrations for days between adjacent sampling dates were estimated by interpolation, to provide estimated or measured TP concentrations for each day. Total phosphorus load was calculated by multiplying daily TP concentration by daily discharge at each structure. Daily loads were summed by month. Monthly TP FWC was calculated by dividing monthly TP load by monthly discharge.

Water column depth profiles of DO (mg/L) and turbidity (NTU) were taken weekly at each station with a YSI 6920 multiparameter water quality sonde (YSI Inc., Yellow Springs, Ohio) during construction. Measurements were taken at mid-channel on each date and at depths of 0.5 m, 1.0 m, and every meter to within 0.5 m of the channel bottom. It was important to measure turbidity throughout the water column because previous studies have found that turbidity plumes can travel deep in the water column and be undetectable at the surface (Koebel *et al.*, 1999). Depth profiles of DO were taken because the formation of a DO gradient (decreasing with depth) can limit habitat availability for aquatic organisms.

2.3. STATISTICS

Turbidity, DO, TP load and TP FWC data were divided into three time periods; baseline (March 5, 1996–May 25, 1999), construction (June 1, 1999–February 28, 2001) and post-construction (April 10, 2001–March 12, 2002) (Table I). A longer baseline period (January 1, 1984–June 1, 1999) was used for TP FWC and TP load data. The purpose of the baseline sampling period was to describe "normal" temporal and spatial trends in turbidity, DO and TP FWC and loads. Statistical analyses were performed using SAS 8.0 (SAS Institute Inc., 1999). All statistics were considered significant at the $p < 0.05$ level. Turbidity and DO data from the construction period and TP FWC and TP load data from all periods were not normally distributed (Shapiro–Wilk test, $p < 0.05$). We transformed the turbidity data by taking a base 10 logarithm, because means were proportional to standard deviations. A square root transformation was used for DO data because means were proportional to variances (Zar, 1996). We were unable to normalize TP FWC and TP load data so non-parametric statistics were used.

Turbidity data were not collected at station AMB during the baseline period and post-construction periods, so data from station S-65A (which is upstream of the construction zone) were used instead. Statistical tests were not used to compare turbidity at S-65A and S-65C during baseline and post-construction periods because mean turbidity at these stations was low and similar enough that any differences were considered to be biologically and chemically insignificant. A t-test was used to compare mean water column turbidity at stations AMB and S-65C for

TABLE I

Water quality parameters studied, monitoring stations and statistical tests performed for each monitoring period. All statistics were considered significant at the $p < 0.05$ level

WQ parameter	Baseline	Construction	Post-construction
Dissolved oxygen	AMB vs. S-65C (t-test)	AMB, K02, K03, K04, K05, K07 (ANOVA)	S-65A vs. S-65C (t-test)
Turbidity	N/A	AMB vs. S-65C (t-test)	N/A
TP Load	S-65A vs. S-65C (Mann–Whitney test)	S-65A vs. S-65C (Mann–Whitney test)	S-65A vs. S-65C (Mann–Whitney test)
TP FWC	S-65A vs. S-65C (Mann–Whitney test)	S-65A vs. S-65C (Mann–Whitney test)	S-65A vs. S-65C (Mann–Whitney test)

the construction period and mean DO concentrations at stations S65-A and S65-C for the baseline and post-construction periods. Because DO concentration can be a major factor controlling habitat suitability for aerobic organisms, mean water column DO concentrations were compared at stations S-65C, K02, K03, K04 K05, K07 and AMB for the construction period using a one-way analysis of variance (ANOVA) and Tukey's HSD test. These tests were used to determine if, and to what extent, local and downstream DO concentration was impacted by construction. The non-parametric Mann–Whitney test was used to compare TP FWC and TP load at S-65A and S-65C for all time periods.

3. Results

3.1. TURBIDITY

Mean turbidity at stations S-65A and S-65C was 5.4 and 2.6 NTU, respectively during the baseline period (Figure 4a). During construction, mean water column turbidity at station S-65C (14.6 NTU) was higher (t-test, $n = 76$, $p < 0.01$) than station AMB (7.6 NTU). Mean post-construction turbidity at stations S-65A and S-65C was 4.5 and 3.6 NTU, respectively. Low turbidity values observed during the post-construction period show that long-term turbidity levels downstream of the construction area were not impacted by Phase I of the restoration project.

Turbidity rarely exceeded 10 NTU at station AMB prior to backfilling; however, a turbidity plume was observed between 4 and 8 m soon after construction began, so station AMB was relocated further north at the end of June 1999 (Figure 5). Turbidity at station AMB usually was <10 NTU from July to October 1999. Surface water turbidity had increased to >20 NTU by the end of November 1999, with higher readings below 6 meters, so station AMB was moved north again in December 1999. Turbidity at AMB remained low from December through most of March 2000. No sampling occurred at station AMB during May–mid-June 2000 because of limited access. Station AMB was moved northward to a river channel receiving ambient water from the north in June 2000 (Figure 3). Turbidity at station AMB remained low (<10 NTU) from June 2000 until the end of the construction period.

Downstream of the construction zone at station S-65C, turbidity remained <20 NTU from June to September 1999, increased in October, and peaked in late November to early December 1999, with values >60 NTU throughout the water column (Figure 5). During this time, highly turbid water from the C-38 backfill area was flowing west and then south into MacArthur Run before re-entering C-38. Another brief increase in turbidity in late March 2000 was likely due to increased suspended sediment from dredging a new river channel (Strayer Run) and increased discharge through Pool C (>60 m^3/s) (Figures 5 and 6a). By June 2000, turbidity at station S-65C decreased below 10 NTU and remained low for the rest of the construction period. Station K03, which was upstream of station S-65C, but still

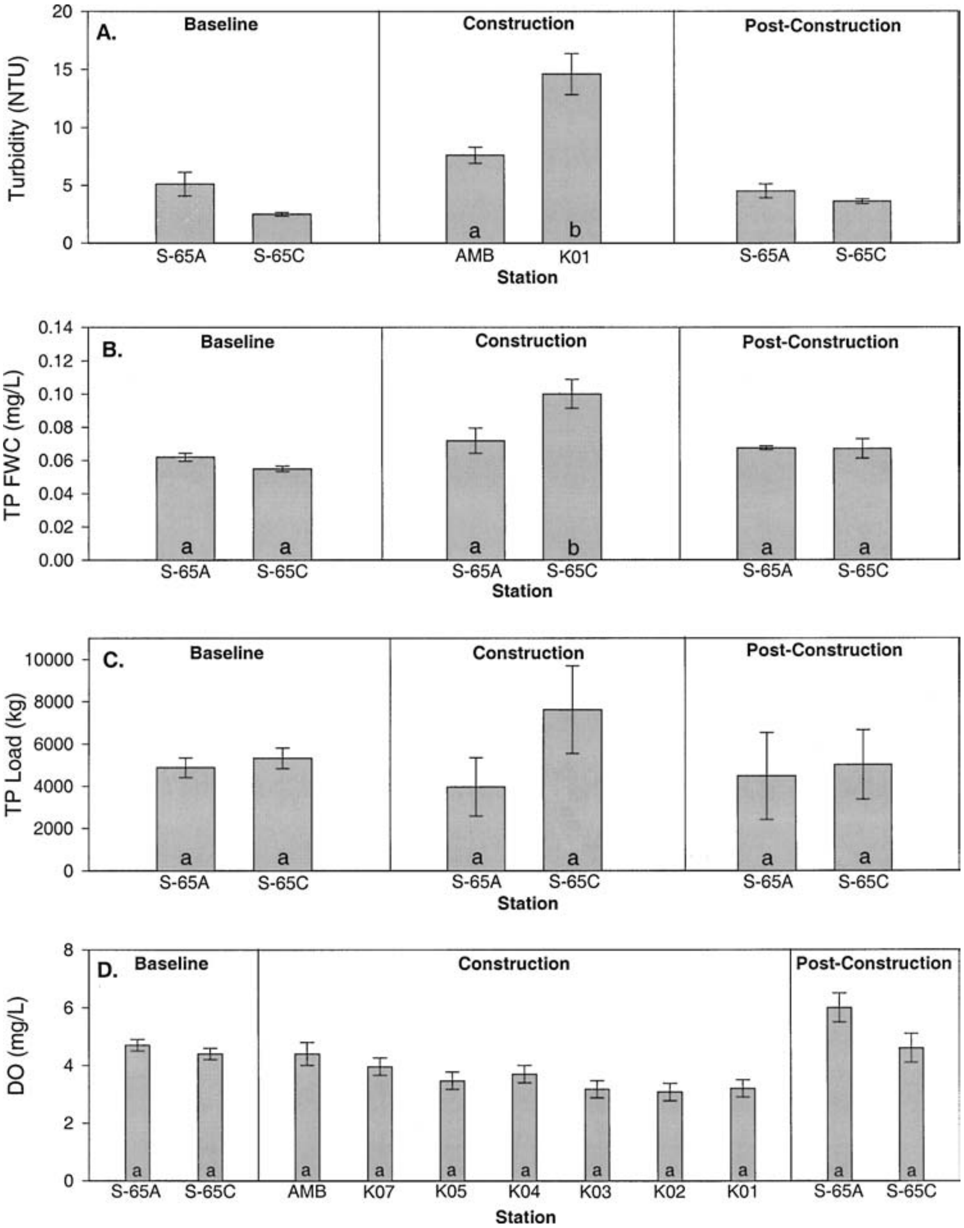

Figure 4. Mean baseline, construction and post-construction turbidity (NTU) (A), total phosphorus flow weighted concentration (mg/L) (B), total phosphorus load (kg) (C) and dissolved oxygen concentration (mg/L) (D) at stations upstream, within and downstream of the construction area. Error bars represent ± one standard error of the mean. Bars with different letters are significantly different at the 0.05 probability level.

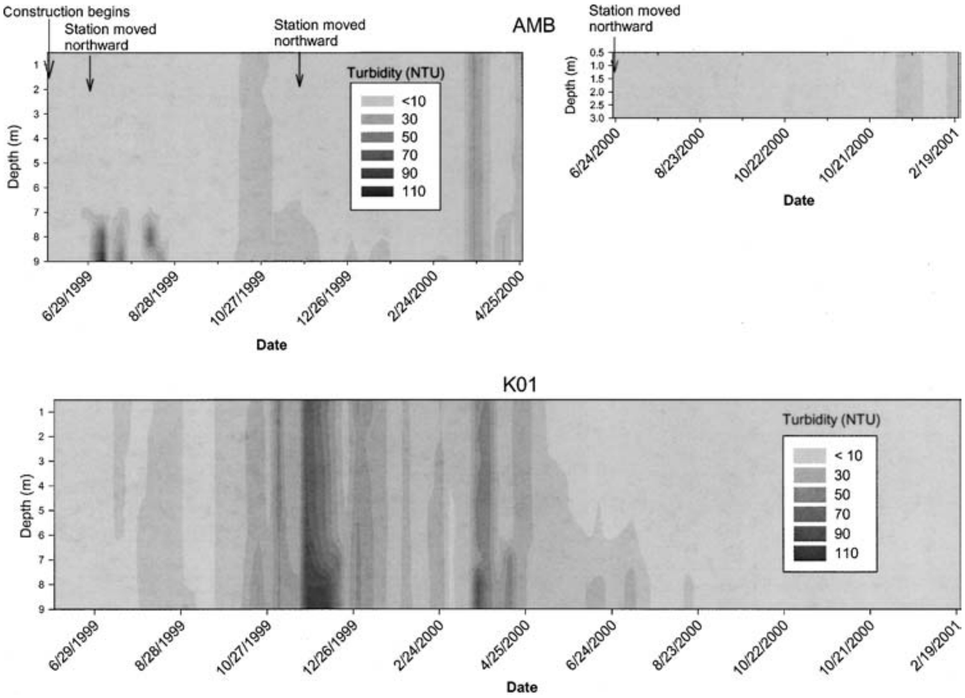

Figure 5. Depth-time diagram of isopleths (a line connecting points having the same numerical value) of turbidity (NTU) at ambient (AMB) and downstream (S-65C) stations.

downstream of the construction zone, exhibited a similar temporal pattern, but turbidity was higher (Figure 7).

Turbidity within the shallower river channel did not vary much with depth. However, considerable temporal variation occurred as discharge from C-38 was diverted to these formerly stagnant channels. MacArthur Run (Figure 3) was the first remnant river channel to receive flow. Turbidity in this run (stations K02 and K04) was less than 10 NTU prior to construction, but immediately increased to >40 NTU after construction of the initial backfill crossing in June 1999 (Figure 6b). Restoration of flow caused large quantities of muck, detritus, and plant material to be flushed from MacArthur Run and carried downstream. Turbidity at K04, increased to >60 NTU twice during summer 1999 and was >100 NTU in November–December 1999 (Figure 6b). Turbidity at K04 was >40 NTU several more times between February and August 2000. In the lower part of MacArthur Run (K02), turbidity followed a similar pattern, but high values were less extreme (Figure 6b). Turbidity at stations K02 and K04 decreased to ambient levels in September 2000–January 2001.

Turbidity at stations K05 and K07 in Micco Bluff Run was low (<12 NTU) until December 1999 when flow was restored to the river channel (Figure 6c). From January through May 2000, turbidity at K05 and K07 was higher, with peak values

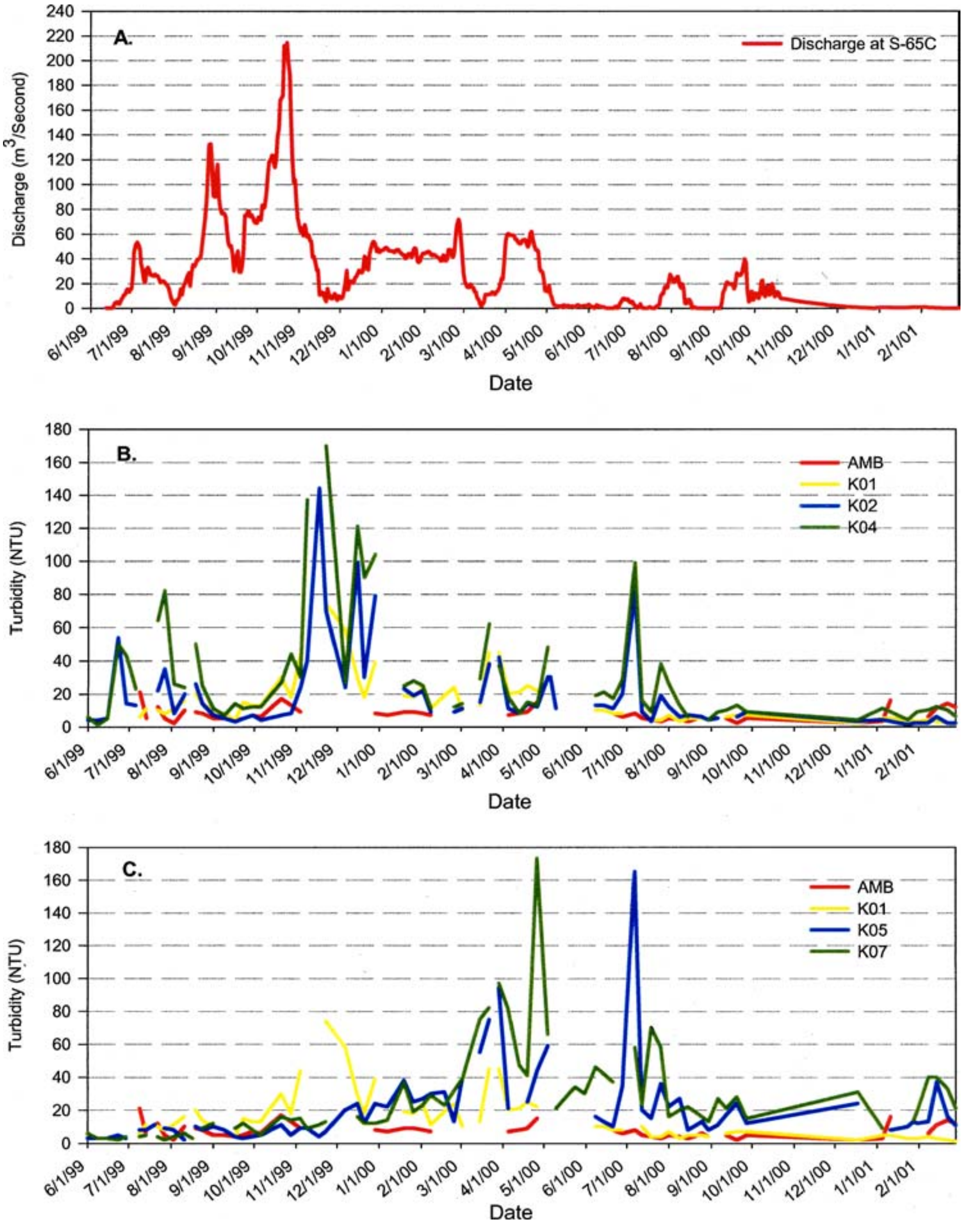

Figure 6. Mean daily discharge (m^3/s) at S-65C (A), mean weekly water column turbidity (NTU) at ambient (AMB) and downstream (S-65C) water quality monitoring stations and at stations within MacArthur Run (B) and Micco Bluff Run (C).

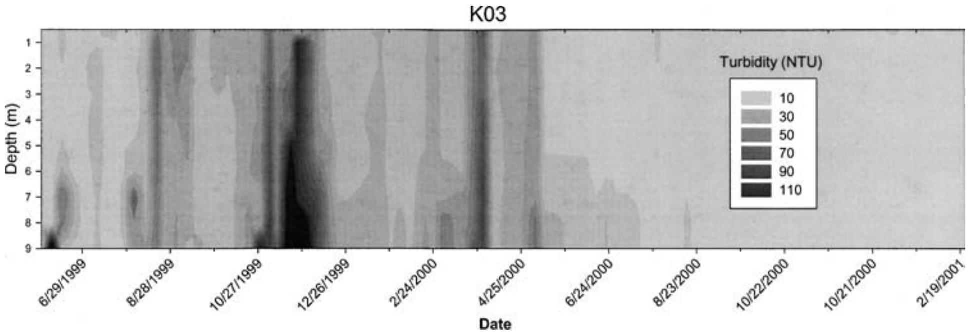

Figure 7. Depth-time diagram of isopleths of turbidity (NTU) at station K03 within C-38, 600 m downstream of initial canal backfilling.

greater than 100 NTU during March and April. High turbidity during these months was associated with backfilling of C-38 north of Micco Bluff Run and discharges >60 m^3/s at S-65C (Figure 6a). By the beginning of June 2000, turbidity at K05 had decreased to <20 NTU. From June until October 2000, turbidity at stations K05 and K07 fluctuated, with peak values >100 NTU. However, turbidity gradually returned to near-ambient levels by the end of construction.

3.2. TOTAL PHOSPHORUS FWC AND LOADS

Baseline mean monthly TP FWC at S-65A and S-65C (0.062 and 0.055 mg/L, respectively) (Figure 4b) were similar (Mann–Whitney test, $n = 186$, $p(X^2) = 0.13$). During the construction period, monthly TP FWC at station S-65C (0.100 mg/L) was higher (Mann–Whitney test, $n = 21$, $p(X^2) < 0.05$) than at S-65A (0.072 mg/L). Post-construction TP FWC at S-65A and S-65C (0.068 and 0.067 mg/L respectively) were similar (Mann–Whitney test, $n = 13$, $p(X^2) = 0.13$). Mean monthly TP loads were similar (Mann–Whitney test, $p(X^2) > 0.05$) at S-65A and S-65C during all time periods (Figure 4c) and ranged from 3961–7608 kg.

During construction, TP FWC at S-65A and S-65C followed a seasonal pattern (Figure 8a). Total phosphorus FWC was highest during the wet season months of July–November and decreased during the dry season months of January–June. Total phosphorus FWC at S-65C was higher than S-65A during most of the construction period. Fortunately, discharge through S-65C was low (0–60 m^3/s) when TP FWC was highest (July 1999 and August 2000), so downstream transport of phosphorus was limited. Total phosphorus FWC at S-65C decreased to baseline levels (≈ 0.06 mg/L) immediately after construction ceased.

During construction, monthly TP loads at S-65A, S-65C and S-65E were highest from August–October 1999, ranging from 10 386–65 077 kg (Figure 8b). Seventy-two percent of TP loading (145 866 kg) to Lake Okeechobee through S-65E during the construction period occurred between July–October 1999. TP loads at S-65C

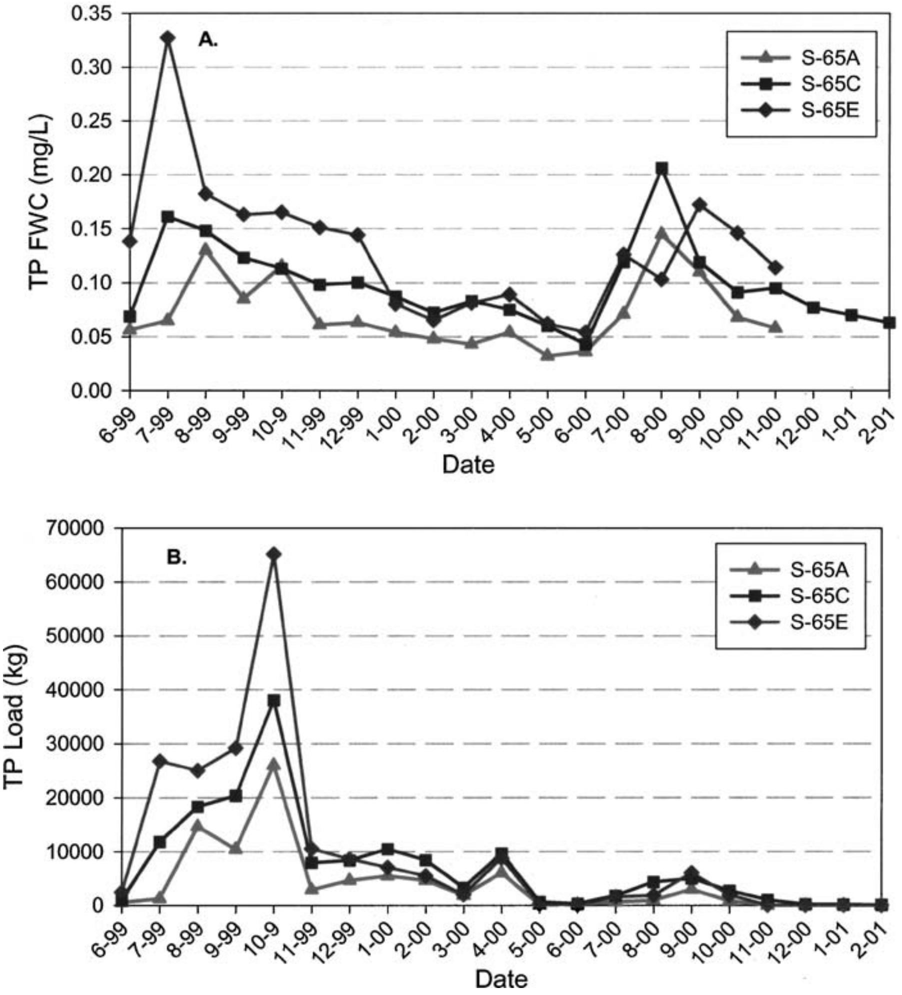

Figure 8. Total phosphorus flow weighted concentration (mg/L) (A) and load (kg) (B) at S-65A, S-65C and S-65E.

and S-65E were relatively low during November–December 1999 when turbidity levels at S-65C were highest (>60 NTU). Total monthly phosphorus loads at all structures ranged from 0–11 000 kg for the remainder of the construction period (Figure 8b).

3.3. DISSOLVED OXYGEN

Mean DO concentrations at stations S-65A and S-65C were similar during the baseline (t-test, $n = 47$, $p = 0.053$), and post-construction (t-test, $n = 47$, $p = 0.327$) periods and ranged from 4.4–5.9 mg/L (Figure 4d). Mean DO concentrations

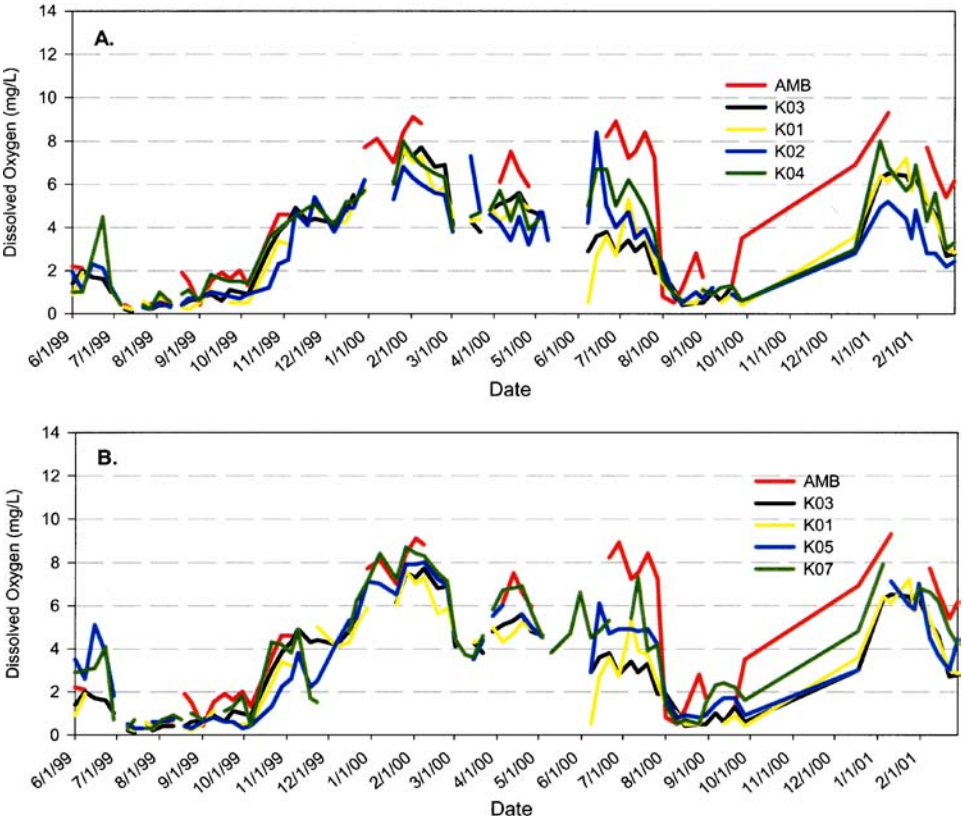

Figure 9. Mean weekly water column dissolved oxygen concentrations (mg/L) at ambient (AMB) and downstream (S-65C) water quality monitoring stations and at stations within MacArthur Run (A) and Micco Bluff Run (B).

at all other stations were similar during the construction period, (ANOVA $n = 80$, $p = 0.11$) ranging from 3.1–4.4 mg/L.

Dissolved oxygen concentrations at stations AMB, K03 and S-65C were very low during summer 1999 and often fell below 2 mg/L (Figures 9 and 10). Dissolved oxygen at these sites increased in mid-October to >2 mg/L and exhibited only slight variability with depth (higher concentrations at the surface) through January 2000. Dissolved oxygen gradients reappeared in February 2000, with higher concentrations near the surface. From March through October 2000, strong DO gradients were observed, with concentrations <2 mg/L at depths greater than 5 m. Generally, DO concentrations were highest during January and February, declined between March and August and increased again from September–December. Vertical DO gradients were strongest from February–August and weakest from September to January.

Re-established flow to MacArthur (stations K02 and K04) and Micco Bluff Run (stations K05 and K07) in mid-June 1999 and December 1999, respectively,

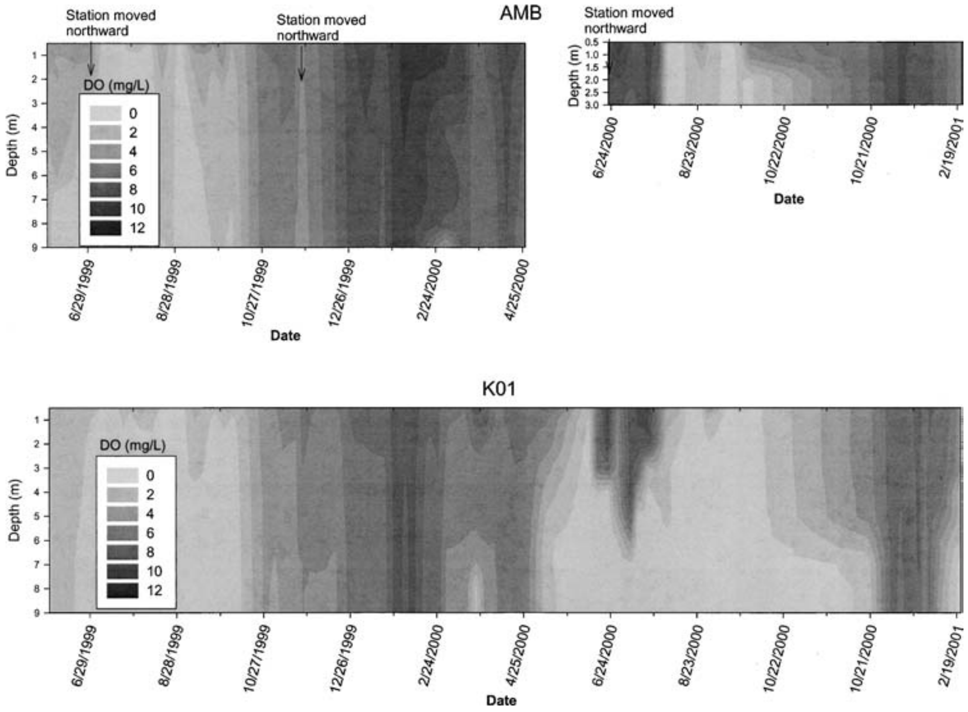

Figure 10. Depth-time diagram of isopleths of dissolved oxygen (mg/L) at ambient (AMB) and downstream (S-65C) water quality monitoring stations.

eliminated DO gradients as flow mixed the entire water column. DO was extremely low in these channels during the summer of 1999 (Figure 9) but increased to >5 mg/L from mid-October 1999 to the end of January 2000. However, these concentrations gradually declined throughout spring.

4. Discussion

Although mean turbidity at station S-65C was twice as high as at station AMB during construction, it is unlikely that the dominant biota of the system were negatively impacted, because high levels only persisted for a short time. Some studies have shown that high turbidity levels can reduce primary production (Lloyd, 1987; LaPerriere *et al.*, 1983). However, there is little evidence that high turbidity will damage stream communities through reduced photosynthetic rates, especially if high levels are not long term (Waters, 1995). When turbidity is high, drift of benthic invertebrates tends to increase due to a decrease in light reaching the channel bottom (Gammon, 1970; Rosenberg and Snow, 1975a,b). However, high turbidity levels would have to be sustained for long periods of time to stimulate drift to the point of severe decreases in populations (Waters, 1995). Tolerance of warmwater fish species to turbidity varies considerably (Muncy *et al.*, 1979). There was no evidence of fish mortality during construction, therefore it is likely that most fish species either tolerated or avoided highly turbid areas.

Turbidity throughout the water column at S-65C was usually less than 10 NTU and only exceeded 35 NTU for approximately 2 weeks during the 21-month construction period. Low turbidity values observed during the post-construction period illustrate that construction did not have a long-term effect on downstream turbidity. Isolating areas of active backfilling from the rest of the canal–river system within "cells" along C-38 proved to be a highly effective construction method for controlling turbidity and should be used during future phases of the restoration project.

Silt screens were deployed across C-38, north of station K03, and in MacArthur Run, north of station K04, in an attempt to control downstream turbidity during construction. These screens appeared to ameliorate turbidity within the top half of the water column. However, particulates moving or diffusing along the bottom of the channel were not contained because the silt screens did not extend deep enough. The turbidity plume generated by backfilling was concentrated below a depth of 4–6 m. Thus, silt screens should extend deeper in the water column to control turbidity more effectively.

Higher TP FWC at S-65C than at S-65A during the construction period indicates some impact from construction. However, because discharge at S-65C was low when TP FWC was high, downstream transport was limited. Higher phosphorus concentrations during the wet season were also observed prior to construction (Jones, 2002). On the basis of DO profiles, sediments in C-38 became anoxic or nearly so during the wet season. Phosphorus trapped in benthic sediments can mobilize and diffuse upward into the water column when the sediments become anoxic (Mortimer, 1941–1942).

Based on similar TP loads at S-65A and S-65C during construction, Phase I of the restoration did not significantly increase downstream loading. A substantial portion of C-38 discharge and TP loading to Lake Okeechobee was from local runoff into Pools D and E. The influence of tributary inflows was greatest in October 1999 when 8–13 cm of rain fell at S-65C, S-65D and S-65E early in the month and Hurricane Irene contributed 2–5 cm of rainfall on October 14–16.

We found that TP levels near this large-scale backfilling project could become quite high at times. Therefore, it is important for projects of this nature to monitor TP and if possible, limit discharge from the construction area until TP levels decline. Furthermore, backfilling activity should be scheduled during the drier months of the year so discharge from the construction area can be limited.

Local and downstream DO concentrations were not affected by construction. Dissolved oxygen concentrations were greater during the dry season due to increased solubility in cooler water temperatures. Additionally, biochemical oxygen demand is generally lower because of cooler water temperatures and slower decomposition rates. Wind-induced aeration also is generally higher during the dry season due to cold fronts (causing increased wind speed) that pass through the region.

The C-38 canal behaved more like a eutrophic reservoir than a river. The canal's depth (9 m) and low flow velocity allowed the formation of a clinograde oxygen curve (higher oxygen at the surface, lower at the bottom) during the spring months. In the summer, as water temperature and respiration increased, oxygen concentrations were severely reduced. Although seasonal variations in DO concentrations are expected to continue after restoration, extended periods of extremely low oxygen should be rare as continuous flow is restored to the system.

There are few studies that quantify the impacts of large-scale construction projects in or near surface waters on water quality. However, the results of our study generally agree with the existing literature. Koebel *et al.* (1999) evaluated changes in turbidity, TP and DO during backfilling of a 330 m section of the C-38 canal. Turbidity near the construction zone increased for several weeks before returning to baseline levels. Silt screens were moderately effective at containing turbid water within the construction zone. Total phosphorus concentrations did not increase during construction. Dissolved oxygen concentrations decreased slightly, but changes were likely due to normal seasonal cycles rather than construction impacts. Shields and Sanders (1986) collected turbidity and TP data before and during construction of the Divide Cut of the Tennessee–Tombigbee waterway. Turbidity and TP significantly increased and DO did not change. Simmons and Watkins (1982) studied the effects of channel excavation on water quality of the Black River in North Carolina. Total suspended solids, TP and DO increased significantly during construction. Unfortunately, none of these studies statistically evaluated pre- and post-construction water quality impacts, which is important in determining if the system has been negatively impacted.

5. Conclusions

The successful completion of the first phase of the Kissimmee River restoration shows that a project of this large scale and scope can be accomplished without causing major impacts on water quality. Although high turbidity was observed within the construction zone at certain times, downstream impacts were minimal and duration of high levels was short. Because impacts were not long-lasting, it is unlikely that construction had long-term negative effects on the major biota of the system. Construction methods used during phase I of the restoration were successful at limiting water quality impacts. Specifically, the utilization of “cells” to contain turbid water during backfilling proved to be effective.

Construction-related increases in TP FWC dissipated as construction activity moved upstream. When TP FWC was elevated, low discharge limited downstream transport of phosphorus. Future large-scale canal backfilling projects should monitor TP and limit discharge from the construction area when levels are elevated. Total phosphorus loading to Lake Okeechobee was not significantly affected by construction, but rather by local inflows south of the construction area. Dissolved oxygen concentrations also were not affected by construction.

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