2001 Monitoring of Mill River
Dissolved Oxygen and Salinity Hamden and New Haven, CT

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Prepared for Regional Water Authority

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Introduction

This report presents results of ongoing studies by the Regional Water Authority (RWA) to document baseline dissolved oxygen (DO) and salinity concentrations in the Mill River downstream of the Lake Whitney water supply reservoir dam. Lake Whitney was used for public water supply from 1862-1991 and The Regional Water Authority will be resuming water withdrawals from the reservoir following construction of a new water treatment plant scheduled for completion in late 2004. The following monitoring results are discussed:

- A short-term monitoring effort was conducted on August 21, 2001 to evaluate DO and salinity concentrations over a full tidal cycle in the Mill River from the Lake Whitney spillway to the English Station Power Plant. The objective of the monitoring was to repeat the August 2000 survey and determine the effects of low flow on DO and salinity concentrations in the river during summer conditions. However, as was the case in 2000, heavy rains preceding the 2001 field effort created unusually high seasonal flows. Thus, the results of the monitoring reflect higher flow rates than typically occur in August.
- In July and August, 2001, the RWA conducted weekly dawn dissolved oxygen and salinity monitoring of the Lake Whitney spillway overflow, the Lake Whitney spillway plunge pool, and the Mill River at the Orange Street Bridge. The purpose was to assess relationships between flow and DO concentrations in the downstream Mill River corridor from the Whitney dam to the Orange Street bridge. The results can be used to assess the DO concentrations necessary in the spillway plunge pool to maintain acceptable DO levels downstream.
- Supplemental data was collected for the same purpose by the RWA on October 25, November 16, and November 19 to assess the effects of moderately low flow conditions that occurred in Fall of 2001.

Dissolved Oxygen and Salinity Monitoring

Short-term Monitoring Study

The August 21 water quality monitoring was conducted by two field teams, one from CH2M Hill (2 persons by boat) and one from the RWA (1 person on foot). DO and salinity concentrations were measured with two hand-held, *in-situ* meters (a YSI Model 85 and a Hydrolab Quanta), which were calibrated simultaneously prior to the surveys to ensure comparability of the results. Four surveys of DO and salinity concentrations in the Mill River, from the dam to the English Station power generating plant downstream of the tidal gates, were conducted from approximately 7:00 AM to 6:00 PM on August 21, 2001 (Table 1) and covered the full tidal cycle.

DO, specific conductance, temperature, and water level change were measured at a total of 17 stations along the river (Figure 1), from Station #0 (in Lake Whitney, just upstream of the dam) to Station #18 (at the English Station power generating plant). Station #2 and Station #3, which were sampled in August of 2000, were not sampled this year. A few stations (#5, #7, #9, #11) were not sampled during the course of the fourth survey, due to time constraints and because DO and salinity measurements were found to be very similar throughout this reach of the river at the time of the survey. One additional station (Station #13B) was added between Stations #13 and #14 (approximately equidistant from both) in order to adequately characterize the salt wedge from the flood (incoming) tide. Because the flood tide did not extend as far upstream as anticipated, there were fewer sampling stations in the vicinity of the salt wedge and therefore this station was added.

Stations #5 through #16 were marked by flagged stakes driven into the riverbed near shore, and water quality measurements were recorded with the YSI Model 85 meter from mid-channel abreast of the stakes. Stations #17 and #18 were monitored by standing on the bridge at the tide gates and the English Station power plant, respectively. Four rounds of measurements were collected between Station #5 and Station #18. Water quality measurements were collected at each location from the surface (1 foot depth), mid-depth, and within one foot of the river bottom. At locations exceeding 5 to 6 feet depth, additional measurements were taken at 2-foot intervals.

Stations #0, #1, and #4 were monitored with the Hydrolab Quanta, and were accessed by standing on the Lake Whitney dam (Station #0), standing alongside the plunge pool (Station #1), or from the foot bridge (Station #4).

The low tide for New Haven, CT on August 21, 2001 was at 7:30 AM, and the high tide occurred at 1:37 PM. There is generally about a 2-hour and 25 minute lag time between high and low tides in the harbor and the Mill River in the vicinity of the foot bridge, corresponding to low and high tides times at the footbridge of 9:55 AM and 4:02 PM, respectively.

Table 1

Dissolved Oxygen/Salinity Surveys Completed on Mill River on August 21, 2001

(Stations downstream of foot bridge)				
Survey #	**Start Time**	**Finish Time**	**Number of Stations**	**Tide Stage**
1	0645 (Station #18)	0950 (Station #5)	14	Low
2	1025 (Station #18)	1230 (Station #5)	14	Low (flood)
3	1325 (Station #18)	1545 (Station #5)	14	High
4	1610 (Station #18)	1748 (Station #6)	11	High (ebb)
Note: Stations 0 through 4 were surveyed simultaneously at closely corresponding time intervals during each survey.				

Weekly Summer and Fall Supplemental Monitoring

In addition to the August 21, 2001 survey, weekly dawn DO and salinity monitoring was conducted by the RWA for the months of July and August, 2001. Weekly data were taken from Stations #0 (spillway), #1 (plunge pool), and #13 (Orange Street). The RWA also conducted DO and salinity monitoring on October 25, November 16, and November 19 2001, which included data from Stations #0. #1, #4 (foot bridge), #13, #16 (north of tide gates), and #17 (south of tide gates). On November 19, a new station (#3a) was created located between Stations 3 and 4 to better define the upstream limit of saltwater intrusion. All data were collected with a Hydrolab Quanta.

Results of Dissolved Oxygen Monitoring

The results of the August 21, 2001 DO monitoring revealed a steady decrease in DO concentrations with increasing distance downstream of East Rock Road (Figure 2). Figure 2 shows DO concentrations as measured at mid-depth for each sampling location. The same trend observed in the mid-depth concentrations was observed in the surface and bottom concentrations. DO concentrations were near saturation in the reach of the river from the dam to East Rock Road, even at dawn under low tide conditions (when lack of oxygen producing photosynthesis typically results in the lowest DO levels) . However, DO concentrations were increasingly lower with distance downstream of East Rock Road during low and flood tide conditions, with concentrations ranging from 4 to 6 mg/L. DO concentrations improved during the peak high tide and ebb tide, with concentrations increasing to about 9 mg/L between Orange

Street and the tide gates. The data collected during the ebb (outgoing) tide (Figure 2) suggest that water with high DO (about 10 mg/L) is backed up by the flood tide upstream of East Rock Bridge, and then moves downstream with the ebb tide.

A minor DO spike was observed directly down current from the tide gates, most likely due to reaeration associated with turbulence as the water passed through the tide gates. A difference of 7.2 inches was measured in water levels at the tide gates, resulting in substantial hydraulic head and turbulent flow on the downstream side of the tide gates during the ebb tide. A similar condition was observed on the upstream side of the gates during the flood tide.

On August 21, 2001, the DO concentrations from the dam to the English Station power plant ranged from 2.9 to 10.6 mg/L. Some of the observed variation was undoubtedly caused by the increased oxygen production from photosynthesis, during daylight hours. However, these data were found to be more variable than the August 1, 2000 DO monitoring data. While the results of the two monitoring events were generally similar, DO was lower for the low tide sampling rounds on August 21, 2001 than it was in 2000, particularly from East Rock Road to the tide gates. The August 1, 2000 monitoring study was conducted after a major rain event, resulting in the high flow of 122 million gallons per day (mgd). Rain also preceded the August 21, 2001 event, and flow was estimated to be 85 mgd on that day.

The decrease in DO concentrations in the area below East Rock Road suggests that an increased biological oxygen demand was placed on the system in this vicinity and downstream. The source of the increased oxygen demand is unknown but the rains that preceded the monitoring event could have contributed storm water runoff and combined sewage load to the system. The CH2M Hill field team detected odors which were possible evidence of combined sewage loading just upstream from the East Rock Bridge on August 21, 2001. In 2000, a rain event also preceded the sampling event, therefore CSO and stormwater discharges to the river were likely. In addition, a stormwater outfall, located just downstream of the Covered Bridge, was sampled by the RWA in October 2000. The lab results from the runoff sample suggest sewage contamination. A Hamden sanitary sewer pump station is located nearby and could be a source of the contamination.

Weekly data were also collected by the RWA throughout the months of July and August, 2001 at Stations #0 (spillway), #1 (plunge pool), and #13 (Orange Street). Data were collected at weekly intervals between 5:00 and 5:45 AM, and therefore represent both flood and ebb tides. These data are shown in Figure 3a to compare the effect of varying flow rates on DO concentrations. The average flow rate for the two months was 51.3 mgd. (Flow is presented in parenthesis at the top of each DO concentration data set.) The highest flow for these months was on July 6, when the flow rate was estimated to be 117 mgd at the spillway. The lowest DO occurred during this high rain fall induced flow rate suggesting that stormwater and CSO discharges could be affecting DO as seen in the August 2001 and 2000 surveys. On August 10, flow was at its lowest, at 29 mgd and a low DO concentration of 4.8 mg/L was measured on this day at Orange St. Although DO in the Lake and Dam were high, there is a possibility that temperature contributed to the low DO at Orange St that day. During the July and August Sampling events the average water temperature was 24.4 °C (75.9 °F) on August 10, 2001 the water temperature was 28.3 °C (82.9 °F). Therefore a lower DO concentration would be expected, as the concentration of oxygen in water is inversely proportional to temperature.

During the July/August weekly sampling, the variation in flow rates (29 to 117 mgd) appeared to have some effect on DO concentrations in the Mill River. The DO concentrations at Station #0 (spillway) ranged from 5.0-10.3 mg/L, from 5.3-9.0 mg/L at the #1 (plunge pool), and 4.8-7.5 at the #13 (Orange Street) station, with the majority of the values falling in the 6 to 8 mg/L range. However, low DO concentrations (less than 6 mg/L) were observed at Orange St. at both the highest and lowest flow rate. Like the August, 2000 and 2001 monitoring data, the weekly data reflect a general decrease in DO downstream. The DO concentrations at Orange Street generally vary in relation to the DO concentrations in the plunge pool (i.e., higher DO concentrations in the plunge pool correlate with higher concentrations at Orange Street) but the values are generally 1 mg/L lower than those in the plunge pool.

Additional DO and salinity data were collected by the RWA on October 25, 2001, November 16, 2001, and November 19, 2001. Data collected October 25 and November 16 were collected between 6:45 am and 8:30 am. Data collected on November 19 were collected between 1:20 pm and 2:55 pm, and therefore would be expected to have higher DO concentrations (as was measured) due to the photosynthesis related increase in DO at mid-day.

Data collected by the RWA during the ebb tide on the morning of October 25, 2001 (Figure 3b) show DO concentrations that are similar to both the August 21, 2001 DO data and the July and August, 2001 weekly data, with the exception of those recorded at the foot bridge. The DO concentration in the near-bottom water at the footbridge was 5 mg/L while the surface layer was 6.5 mg/L. This bottom water DO concentration is lower than both DO concentrations observed at the tide gates on the same day (6 to 7 mg/L), and those recorded at the foot bridge on August 21, 2001 (approximately 8 to 10 mg/L). This is possibly due to the salt wedge extending further upstream (Figures 4a and 4b) on October 25, 2001 and the lack of mixing between fully aerated surface waters and bottom waters which assimilate the full sediment oxygen demand. However, the salt wedge reached the footbridge on November 16th as well (Figure 4b), and the DO concentration on this day was much higher, 9.3 mg/L at Orange Street and 8.6 mg/L at the Footbridge (Figure 3b). Therefore, the differences in DO concentrations could be attributed to water temperature differences in the samples. On October 25, 2001 the average water temperature was 16.6 °C (61.9 °F) and on November 16, 2001 the average water temperature was 10.1 °C (50.2 °F). A higher DO concentration is to be expected when the water temperature is lower.

The November 16, 2001 DO data follows the same pattern as the July and August weekly sampled data. The DO rises slightly as the water goes over the dam due to aeration and then decreases as it goes downstream. The November 19, 2001 does not follow this pattern. This is most likely due to the fact that the November 19th sample was taken in the afternoon when DO is higher due to photosynthesis.

DO concentrations varied considerably between flood and ebb tide conditions throughout the sampling period. The average DO concentration over the entire sampling period was 6.6 mg/L with a standard deviation of 1.32. The average DO concentration for ebb tides was 6.0 mg/L with a standard deviation of 1.15. The average DO concentration for flood tides was 7.4 mg/L with a standard deviation of 1.14. These data correlate with the August 21, 2001 data, which show that the average DO concentration was greater during flood tide than during ebb tide. (The November 19, 2001 data was not used in this analysis due to the fact the sample was taken in the afternoon and therefore photosynthesis had an effect on the DO concentration of the sample, biasing it high.)

The relationship between DO concentrations in the lake and DO concentrations in the plunge pool (dam) was analyzed. The lake was at 100% DO saturation on July 13, August 3, August, 17 and August 24. On these dates DO concentration dropped as the water went over the dam and into the plunge pool. On the remaining dates, when the lake was not saturated with DO, there was generally an increase in DO as the water went over the dam into the plunge pool. These data suggest that when lake DO is less than 100% saturation there is an aerating effect, which results in higher DO in the plunge pool. When lake DO is greater than 100% saturation, the action of the waterfall drives off some of the DO, resulting in lower DO concentrations in the plunge pool than in the lake.

Results of Salinity Monitoring

Salinity monitoring revealed that the rain that preceded the August 21, 2001 monitoring suppressed the upstream migration of the salt wedge during high tide to the same extent as it had in 2000 (Figure 5). Salinity concentrations between Orange Street and the tide gates ranged from 0 ppt (at Orange Street) to 16 ppt (at the tide gates).

During the peak high tide on August 21, 2001 the salt wedge extended only to Orange Street (Station #13), as it did in the 2000 survey. This contrasts sharply with the results of previous monitoring, conducted in 1998 during very low flow conditions, when the salt wedge extended upstream as far as the area between East Rock Road and the foot bridge. Thus, the intermediate flow present on August 21, 2001 appeared to suppress the upstream intrusion of the salt wedge as did the higher flow during the 2000 survey.

The October 25, 2001 data confirm that the salt wedge does migrate upstream as flow decreases, as high salinities were recorded in the bottom water layer at the footbridge on that day, when flow was estimated to be 32 mgd. This was also confirmed by sampling on November 16 and 19. The footbridge is upstream of a nearby freshwater tidal marsh on the west side of the river, which contains a marsh vegetation transect being monitored by the RWA, as well as a second freshwater tidal marsh transect located downstream of East Rock Road. The limit of saltwater intrusion on November was located between Stations #3 and #3a and is probably limited by the progressive shallowness of the river near Station #3. Because of its higher density, this incoming salt water forms as a bottom layer of water beneath the outgoing freshwater. Low lying portions of the freshwater tidal marsh are therefore not likely to be exposed to high salinity water as shallow areas with emergent vegetation will be inundated with this surface layer of freshwater. Higher areas of the marsh will also be unaffected as they are only inundated during spring or other periods of high flow, when salinities are low (Rogers, 1998).

Conclusions

- The purpose of the summer monitoring program was primarily to assess the impacts of low flows on the Mill River, however during both 2000 and 2001, the August flows were higher than expected for summer conditions. The high flows and accompanying rain events that occurred in August 2000 and 2001 indicate river dissolved oxygen concentrations can be negatively affected during storm events, especially downstream of East Rock Road. These storm events can produce run off high in biochemical oxygen demand which can significantly lower oxygen concentrations. Storm events can also produce combined sewer overflows (CSOs), as indicated by odors strongly suggestive of sewage inputs to the river noted following a rain event during the 2001 August study. Inputs of oxygen demanding organic materials contained in CSOs in the New Haven portion of the river and stormwater runoff from the overall watershed appear to be significant contributors to low dissolved oxygen concentrations following storm events. These factors will negatively affect downstream dissolved oxygen concentrations regardless of the RWA's efforts to maintain adequate minimum flows and dissolved oxygen at the Lake Whitney dam.
- The Mill River tide gates impede but do not prevent the input of saltwater from the flood tide. During the high flow conditions that occurred in August of 2000 and 2001, freshwater flow impeded the intrusion of the salt wedge to the extent that the salt wedge only reached the area just downstream of the Orange Street Bridge.

As flows decreased in the fall of 2001, the salt wedge extended upstream of the footbridge and the nearby freshwater tidal marsh. Because of its higher density, this incoming salt water forms as a bottom layer of water beneath the outgoing freshwater. Vegetation of the lower freshwater tidal marsh are not likely to be exposed to the higher salinity water as shallow emergent areas will be inundated by the surface freshwater layer. Higher areas of the marsh will also be unaffected as they are only inundated during spring or other periods of high flow, when the salt wedge is pushed further down-river.

Figure 1: LOCATIONS SAMPLED DURING THE DISSOLVED OXYGEN/SALINITY MONITORING ON THE MILL RIVER

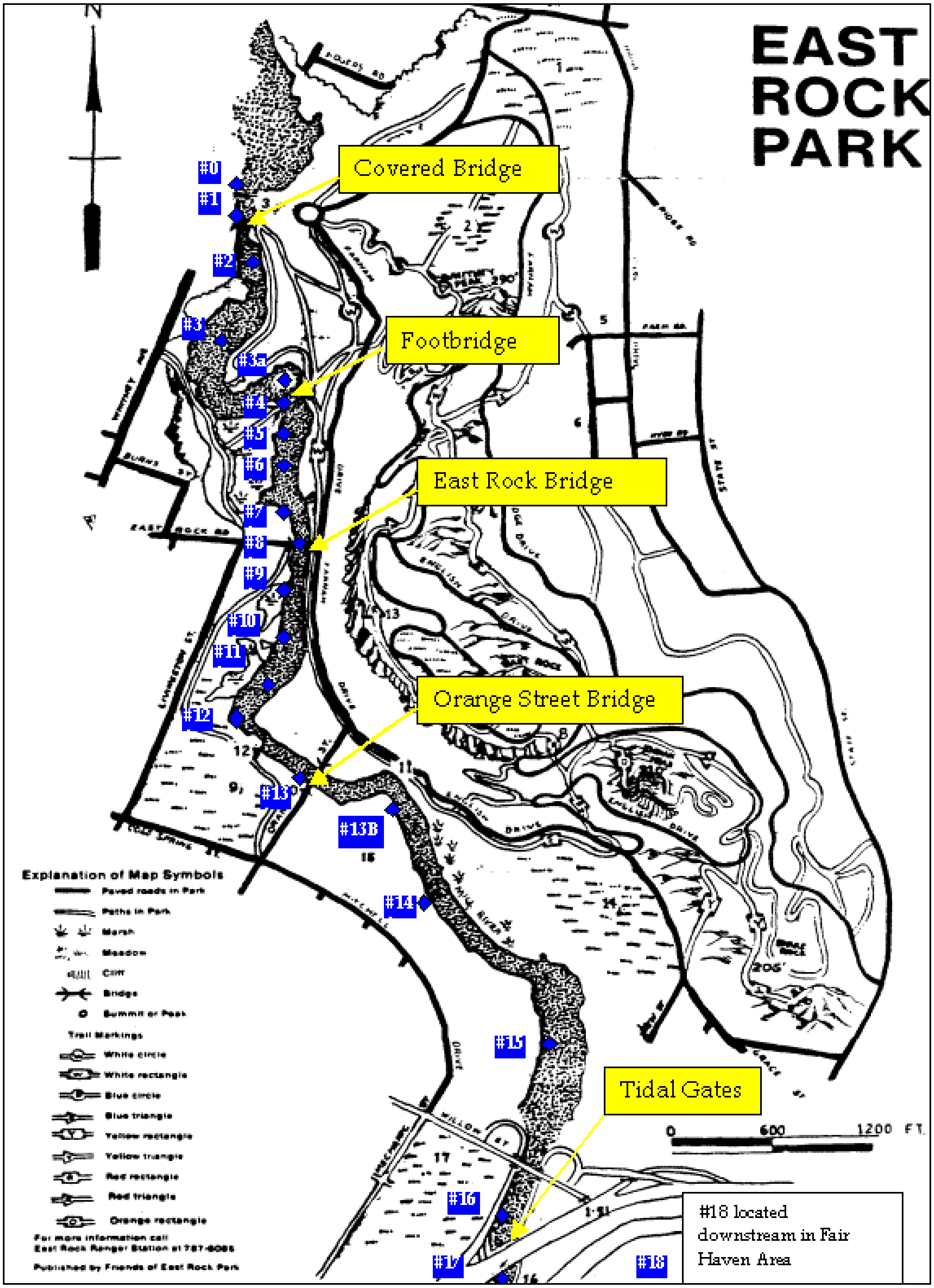

Figure 2. Dissolved Oxygen Concentrations in the Mill River (August 21, 2001):

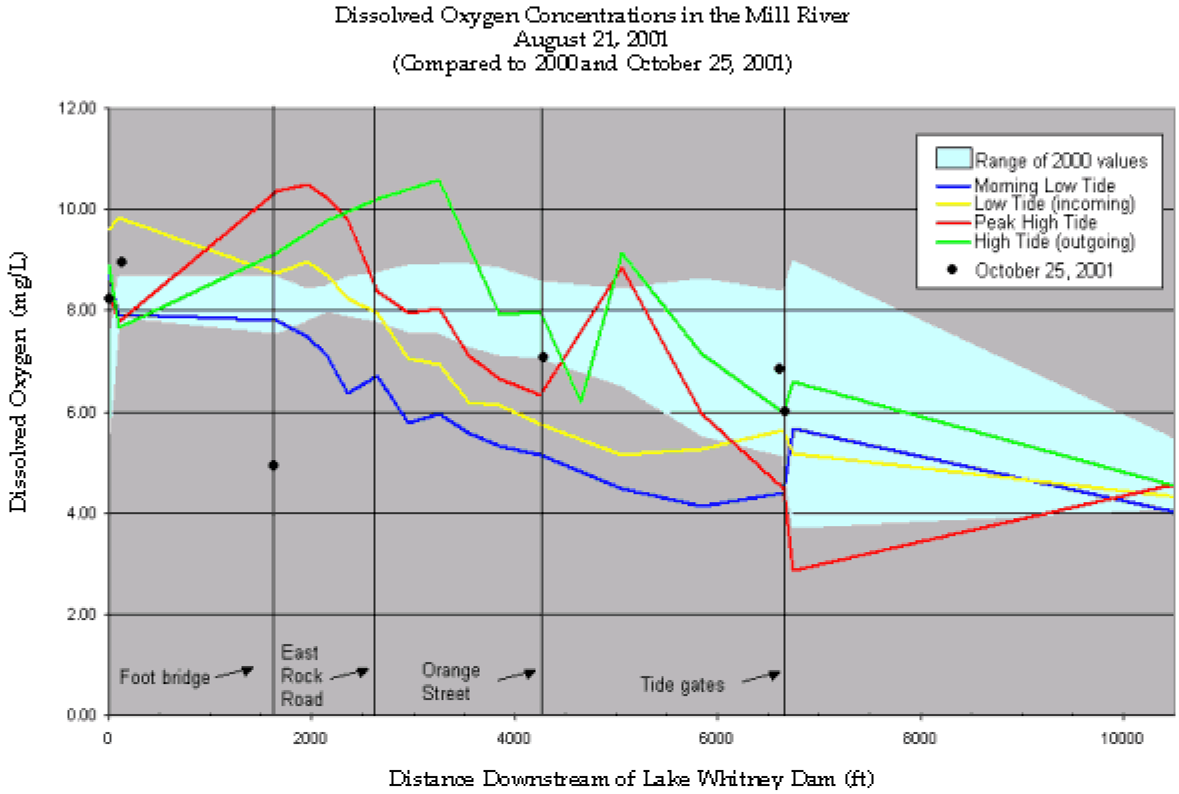

Figure 3a. Dissolved Oxygen Concentrations in the Mill River (2001):

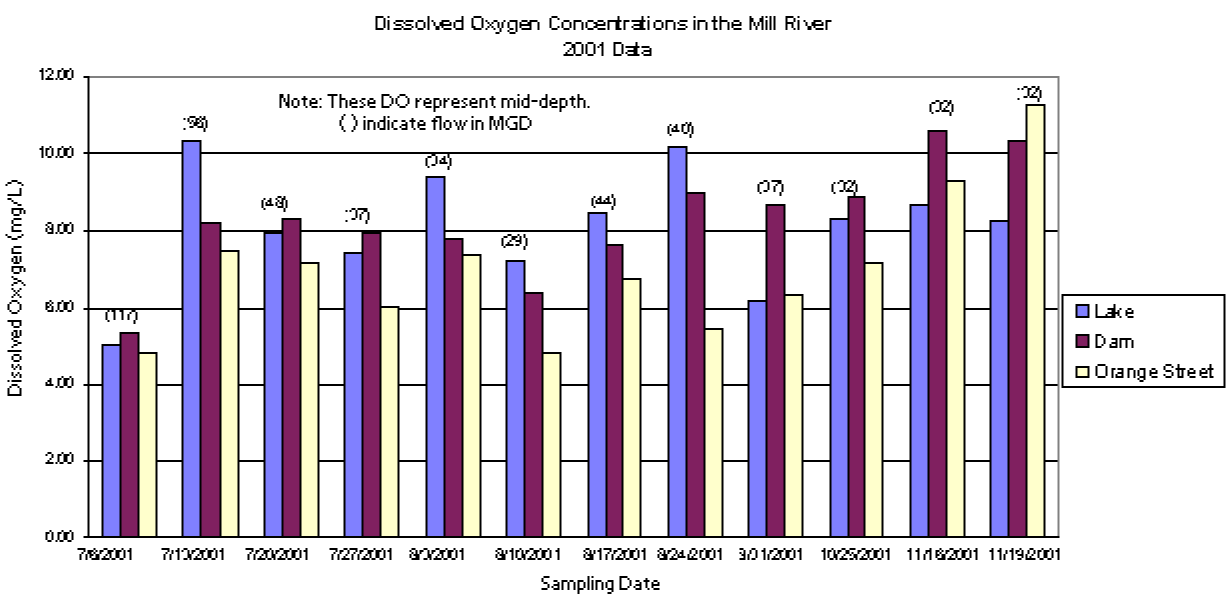

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Figure 3b. Dissolved Oxygen Concentrations in the Mill River

October and November, 2001 Data:

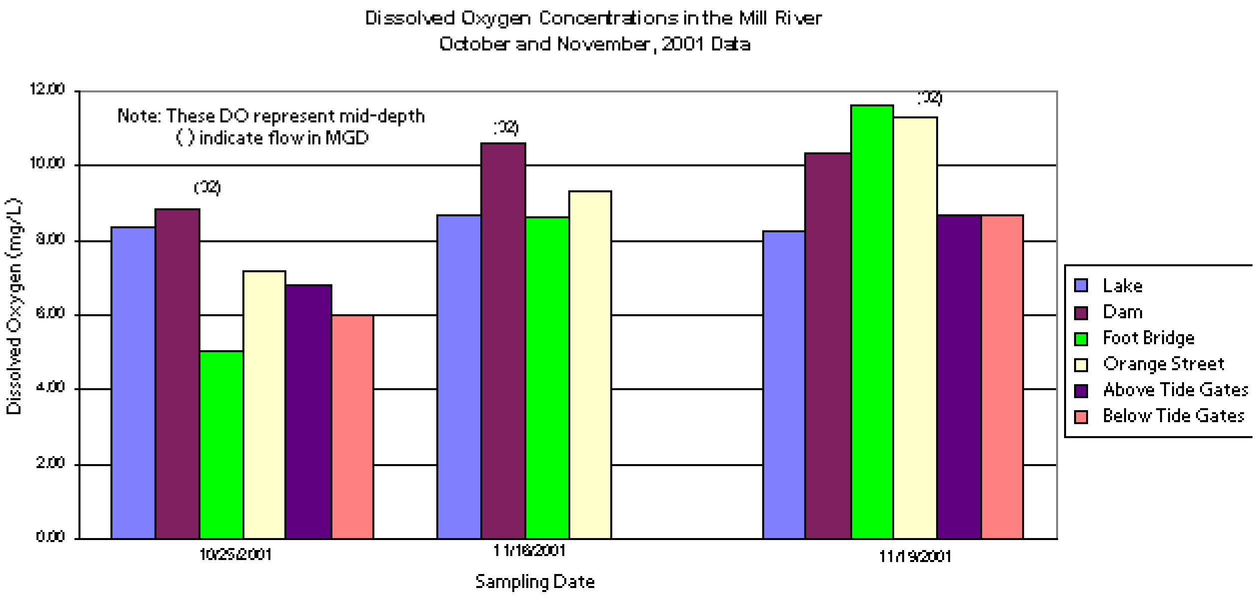

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Figure 4a. Salinity in the Mill River

2001 Data:

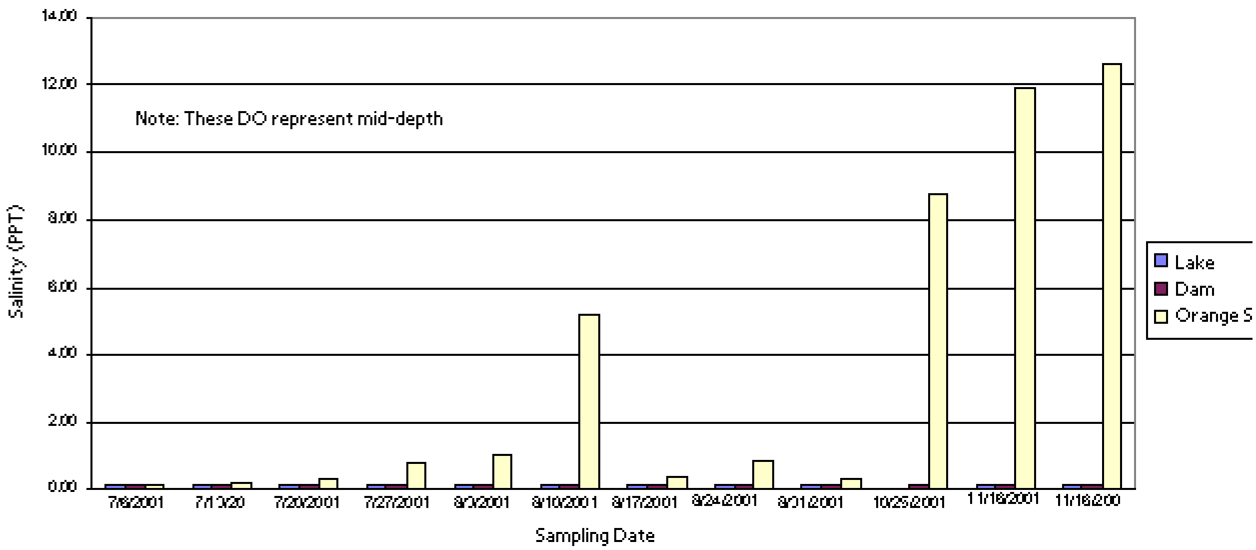

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Figure 4b. Salinity in the Mill River

2001 October / November Data:

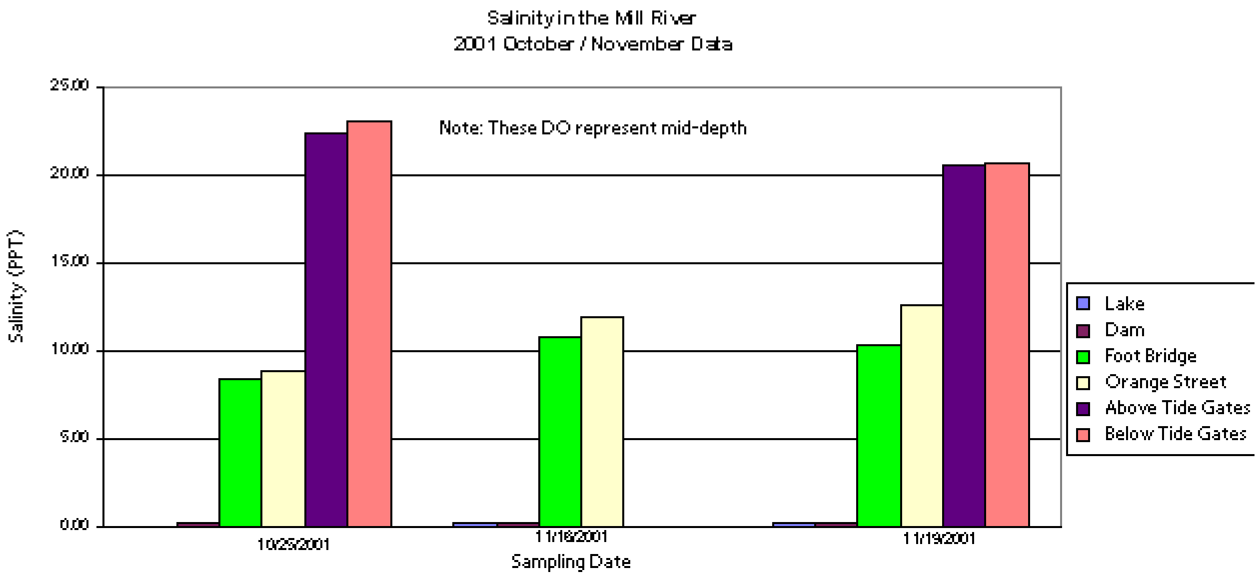

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Figure 5. Salinity Concentrations in the Mill River

August 21, 2001 (Compared to October 25, 2001):