Lower Deschutes River
Dissolved Oxygen Study, 1999

Pelton Round Butte Hydroelectric Project

FERC No. 2030

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INTRODUCTION

The Pelton Round Butte hydroelectric project (Project; FERC No. 2030) is located on the Deschutes River near Madras in central Oregon. The Project consists of three dams: Round Butte Dam, near River Mile (RM) 110, which forms Lake Billy Chinook; Pelton Dam, near RM 104, which forms Lake Simtustus; and the Reregulating Dam, near RM 100. Water is released from deep in the reservoirs (270 ft in Lake Billy Chinook, 150 ft in Lake Simtustus, and 40 ft in the Reregulating pool) and passes through turbines at all three dams. No water is spilled at any of the dams during normal operation.

The Deschutes River below the Project from the Reregulating Dam to the mouth of the White River (RM 46) is included on the Oregon Department of Environmental Quality (ODEQ) 303d list of water quality limited water bodies because it fails to meet the standard for dissolved oxygen (DO) for spawning salmonids (11 mg/L or 95 percent saturation) during part of the year (October 1 to July 31) (ODEQ 1998; CTWSRO 1998). Measurements made immediately below the Project from mid-summer to early fall have sometimes been below the existing water quality standard for cold-water aquatic life (8 mg/L or 90 percent saturation). This has raised concern that the intergravel DO concentration in the water flowing through the riverbed gravel may fall below the minimum intergravel DO standard (6 mg/L) as well.

The salmonids of concern during the time period from mid-summer to early fall are steelhead/rainbow trout *Oncorhynchus mykiss* and fall chinook salmon *O. tshawytscha*. Steelhead spawning occurs between the middle of March and the end of May (Zimmerman and Reeves 1998). Rainbow trout in the Deschutes River spawn primarily during April through August with peak spawning in early June and emergence occurring as late as September (Huntington 1985; Zimmerman and Reeves 1996, 1998). Fall chinook spawn primarily during October and November with some spawning occurring in late September and early December. Emergence is usually completed by May of the following year (Aney et al.1967; Huntington 1985; Jonasson and Lindsay 1988).

Earlier studies (Raymond et al. 1997, 1998) have shown that water leaving the Project through the Reregulating Dam turbine has DO concentrations below standards during late summer. Although the water leaving the Project sometimes fails to meet the existing ambient DO water quality standard, the river water rapidly reoxygenates as a result of physical and biological processes (Raymond et al. 1998, Eilers et al. in preparation).

PURPOSE

The purpose of the present study was to investigate DO levels in the Deschutes River downstream of the Project under several operating scenarios. The specific objectives were to:

1. Determine the ambient and intergravel DO concentrations, and the relation between the two, in artificial redds at selected sites in the upper portion of the lower Deschutes River.

2. Determine the effects of various levels of aeration on the ambient and intergravel DO at these same sites.

METHODS

Four locations in the Deschutes River where salmon, steelhead, and resident trout are known to spawn (Steve Pribyl, Oregon Department of Fish and Wildlife, personal communication) were chosen at intervals below the Reregulating Dam in close proximity to the Project. Artificial salmon redds were constructed at each site with provision for measuring the DO concentration of water passing through the redds. Measurements were made in the redds and in the ambient water over an 8-day period while the amount of water spilled at the Reregulating Dam was changed from none to 100 percent in increments at 48-hour intervals.

Locations

The four sites and distances downstream from the Reregulating Dam (RM 100) were as follows:

1. *Rereg*: Pelton Trap, 0.2 km (RM 100), (upstream of old trap entrance)

2. *Dizney*: Dizney Island, 1.6 km (RM 99), (side channel of island)

3. *Hwy 26*: below Highway 26 bridge, 5.6 km (RM 96), (downstream of Shitike Creek)

4. *Trout*: Trout Creek area, 20.9 km (RM 87), (about 500 m downstream of Trout Creek and roughly 300 m downstream of Trout Creek Rapid)

Redds

Three artificial redds were constructed at each site using a large-bladed hoe. The hoe handle was held vertically with the blade contacting the substrate surface and was moved vigorously up and down to create a turbulent water current that entrained sediment and gravel into the water column. This method was thought to best mimic the creation of actual redds. A depression (egg pocket) was made approximately 25 cm deep into the gravel. A 1.5-m long standpipe was placed in the egg pocket and covered with gravel, from upstream of the egg pocket, to a depth of about 25 cm (Aney et al. 1967; Chapman 1988). Two of the redds at each site had standpipes with an inside diameter of 3 cm, and one redd at each site had a standpipe of 5.5 cm diameter. Twenty 5-mm holes were drilled in the lower 10 cm of each pipe to facilitate water exchange. A YSI™ multi-parameter water quality data sonde with data logging capability was installed to the depth of the egg pocket in the redd with the larger diameter standpipe. A Hydrolab™ recording multi-parameter water quality probe was placed in the river just upstream of the redd containing the multi-parameter data sonde. The redds were located where the water velocity was between 0.5 and 1.0 m/s. Average water depth over the redds was 0.42 m, and the average area of the redds was 2.1 m^2.

Samples and Analysis

DO concentration, pH, conductivity, and temperature were recorded at hourly intervals in the ambient water and in one redd at each site. DO concentration, pH, conductivity, and temperature were also measured using handheld field instruments at least twice per day in all redds at each site as backup. Ambient and intergravel DO within all redd standpipes were measured two times per day (between 7:00 AM and 6:00 PM) at each site using Winkler titration (ODEQ 1997). Water samples were collected each day for laboratory analysis of suspended solids, nutrients (N and P), and total organic carbon. Water samples were collected using a 12-volt pump with a 2-m long plastic tube inserted to the bottom of a standpipe. The pump was primed and allowed to run long enough to purge the standpipe of any sediment-laden standing water and to ensure no air bubbles remained in the pump system (ODEQ 1997). A 300-ml BOD bottle was then filled and allowed to overflow three times its volume before inserting the stopper (Standard Methods 1998).

Aeration Treatments

The study was conducted in mid-September (September 14 through 22). Earlier studies (Raymond et al. 1997, 1998) suggested that DO concentrations in the Project discharge would be lowest during September.

Over the duration of the 8-day study, four aeration treatments were applied. Aeration was achieved by spilling different proportions of total flow at the Reregulating Dam. The proportions used were no spill (100 percent of flow passing through the turbine) 1/3 spill, 2/3 spill, and 3/3 (full) spill. The planned duration of each treatment was 48 hours to allow for equilibration of DO readings at all sites. The actual timing and duration of the each treatment are shown in Table 1.

Table 1. Magnitude, times, and duration of aeration treatments for the Lower Deschutes River Dissolved Oxygen Study, 1999.

Treatment	Start		Finish		Hours
No spill	09/14/1999	9:00 AM	09/16/1999	9:00 AM	48
1/3 spill	09/16/1999	9:00 AM	09/18/1999	9:00 AM	48
2/3 spill	09/18/1999	9:00 AM	09/18/1999	7:30 PM	10.5
Pelton Dam spill	09/18/1999	4:00 PM	09/20/1999	3:00 PM	47
3/3 spill	09/20/1999	8:30 PM	09/22/1999	12:00 PM	39.5

During the study, a range fire damaged a critical electrical transmission line and forced the shut-down of generation at Pelton Dam. As a consequence, 100 percent of the generation flow at Pelton Dam was spilled over the dam for approximately 48 hours during the study (Table 1). This occurred during most of the 2/3 spill treatment and resulted in less data collection for this treatment. During the period of full spill from Pelton Dam, the spill replaced generation flow. As a result, the amount of spill varied from about 7,000 cfs during peak generation at Round Butte Dam to 0 cfs during the night, when generation at Round Butte Dam did not occur. This spill provided considerable aeration to water entering the Reregulating pool.

Dissolved Oxygen Methodology

Winkler titration is the method preferred by ODEQ for DO measurements. However, for several reasons, the results of the Winkler analysis do not provide an adequate picture of the changes in DO that resulted from modifications in spill. All the Winkler tests were done during the daytime, when DO is likely to be elevated because of photosynthetic activity in the river. In addition, the logistics of sample collection limited the number of samples to two per day per location, which makes it difficult to determine the daily cycle of change in DO concentration. To circumvent these problems, hourly DO readings were collected in the river and from within one redd at each location using *in situ* instruments with data logging capability.

Several factors can affect the accuracy of instrumental DO analysis. Differences in calibration can cause instruments to give different readings under the same conditions. Changes in altitude from the point of calibration to the point of use can alter the calibration value, and the calibration value of the instrument can drift over time. To compensate for these possible variables, all the instrument data were normalized to the Winkler titration data collected at the same site. This essentially was a re-calibration of the instruments every time a Winkler titration was done. The normalized data were then used for all subsequent analysis. The results of the normalization process are shown in Appendix 1.

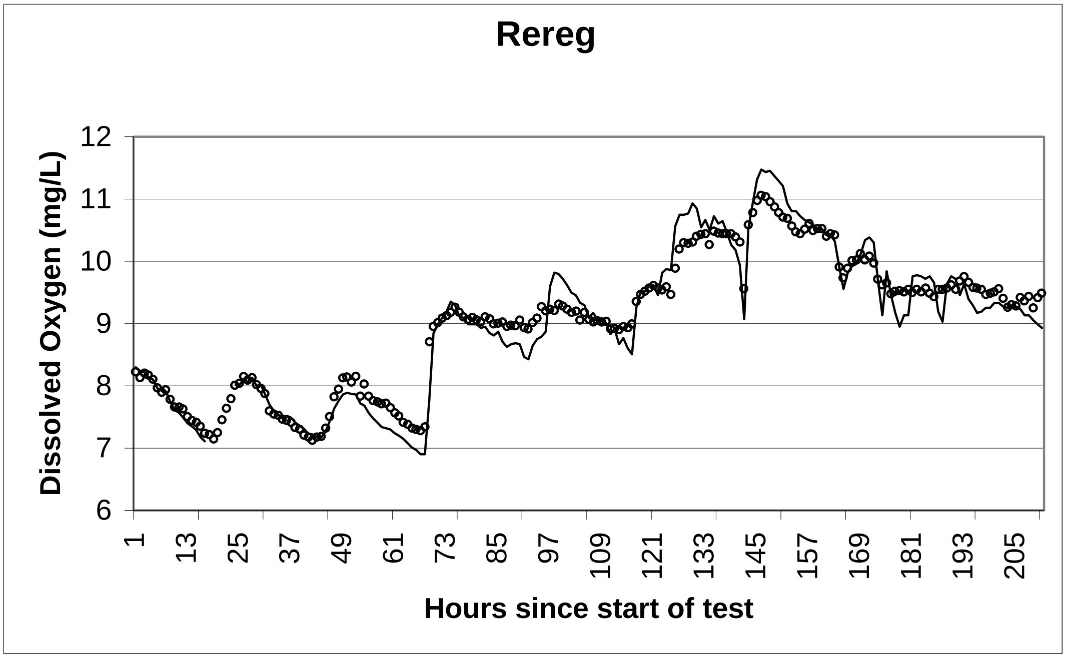
RESULTS AND DISCUSSION

Ambient vs Intergravel DO

Analysis of variance (ANOVA) of Winkler titration data using repeated measures revealed that, within each location, there was no significant difference (P=0.05) between redds or between the ambient and intergravel DO concentration. Comparisons of corrected hourly instrument data for ambient and intergravel DO concentrations showed that there was no significant difference at the Rereg and Dizney locations, but at the Hwy 26 and Trout locations, concentrations did differ significantly (P<0.05). Ambient and intergravel DO concentrations for each location are presented in Figures 1 and 2.

Aeration Treatments

The 1/3 spill and full spill treatments at the Reregulating Dam resulted in statistically significant increases in Winkler ambient DO, compared to no spill, at Rereg, Dizney, and Hwy 26, but not at Trout (Table 2). Full spill at Pelton Dam resulted in statistically significant increases in Winkler ambient DO at all four locations (P<0.05, repeated measures ANOVA).



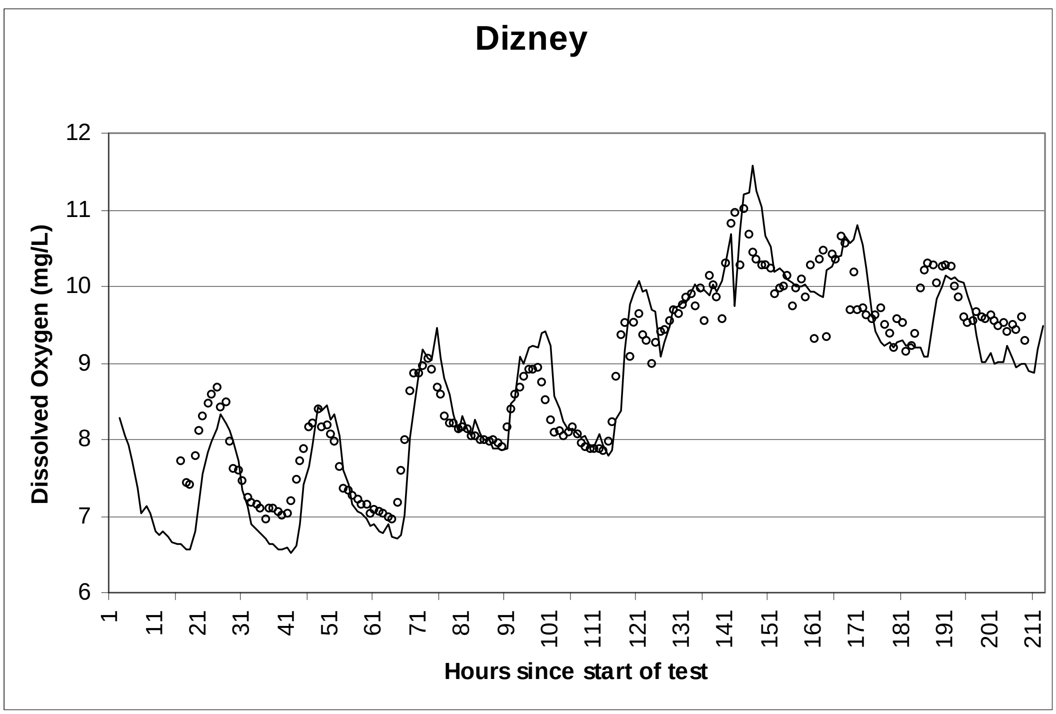
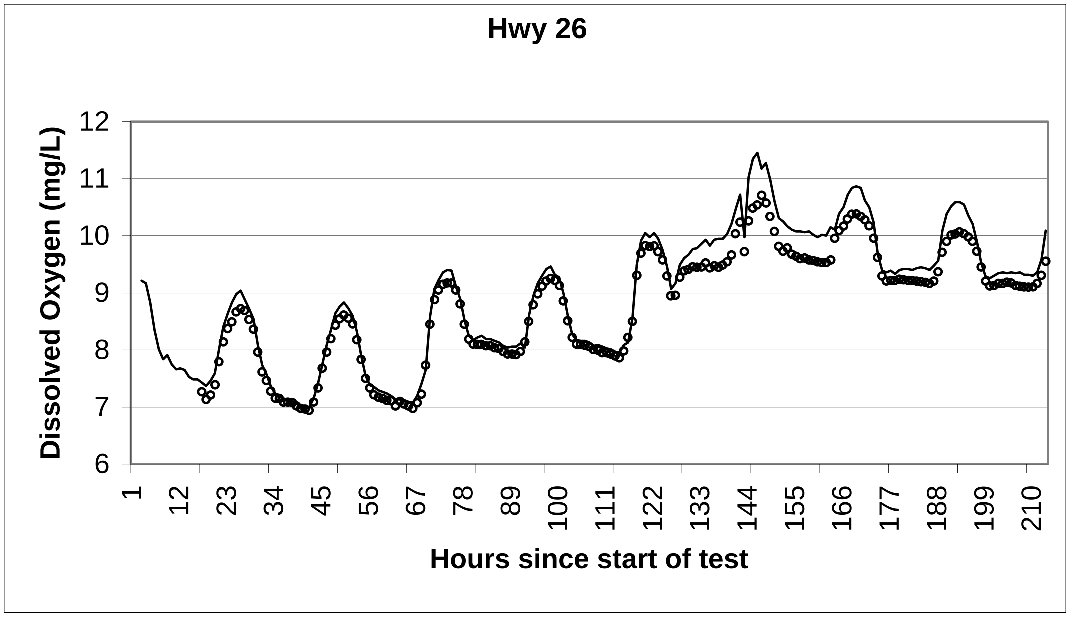


Figure 1. Ambient dissolved oxygen concentration (solid line) and intergravel dissolved oxygen concentration (circles) measured at Rereg and Dizney sites in the lower Deschutes River, September 14–22, 1999.



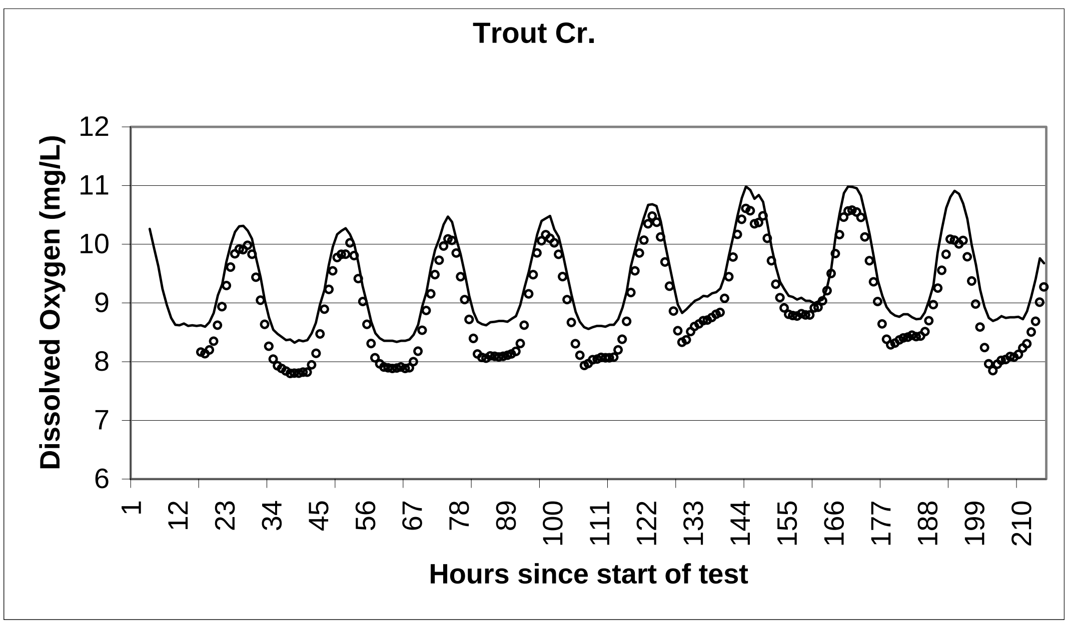


Figure 2. Ambient dissolved oxygen concentration (line) and intergravel dissolved oxygen concentration (circles) measured at Hwy 26 and Trout sites in the lower Deschutes River, September 14–22, 1999.

Table 2. The effects of varying amounts of spill from Reregulating Dam on Winkler ambient DO concentration in the Deschutes River (DO mean value, mg/L).

Location	No spill	1/3 spill	3/3 spill	Pelton spill
Rereg	7.46	8.67	9.20	9.99
Dizney	7.86	8.49	9.40	10.42
Hwy 26	8.06	8.64	9.33	10.22
Trout	9.22	9.18	9.39	10.20

The effect of spill on ambient DO was not proportional to the amount of water spilled. The effects of increasing spill from none to 1/3 was greater than the effect of increasing spill from 1/3 to full. The increase in Winkler ambient DO concentration between 1/3 spill and full spill was not statistically significant at Rereg, Hwy 26, or Trout ($P>0.05$, Tukey-Kramer multiple comparison test, paired values).

Although unplanned, the effect of full spill at Pelton Dam provides insight into what might be the maximum possible increase in ambient DO concentration if no consideration were given to operational requirements. The height and configuration of the spillway at Pelton Dam provides ample opportunity for reaeration. The increase in Winkler DO under conditions of full spill at Pelton Dam was highly significant ($P<0.001$) at all four locations.

The effect of the different levels of spill on ambient and intergravel DO, as measured by hourly corrected instrument data, is summarized in Figure 3.[1]

1 Box plots enable comparison of data in terms of distribution, symmetry, and scale. The limits of the box correspond to the 1st and 3rd quartiles (Q1 and Q3), and the whiskers to Q1-1.5(Q3-Q1) and Q3+1.5(Q3-Q1), respectively. Data that are outside of these whiskers are considered potential outliers and are printed as open circles. The minimum and maximum are printed as solid circles.

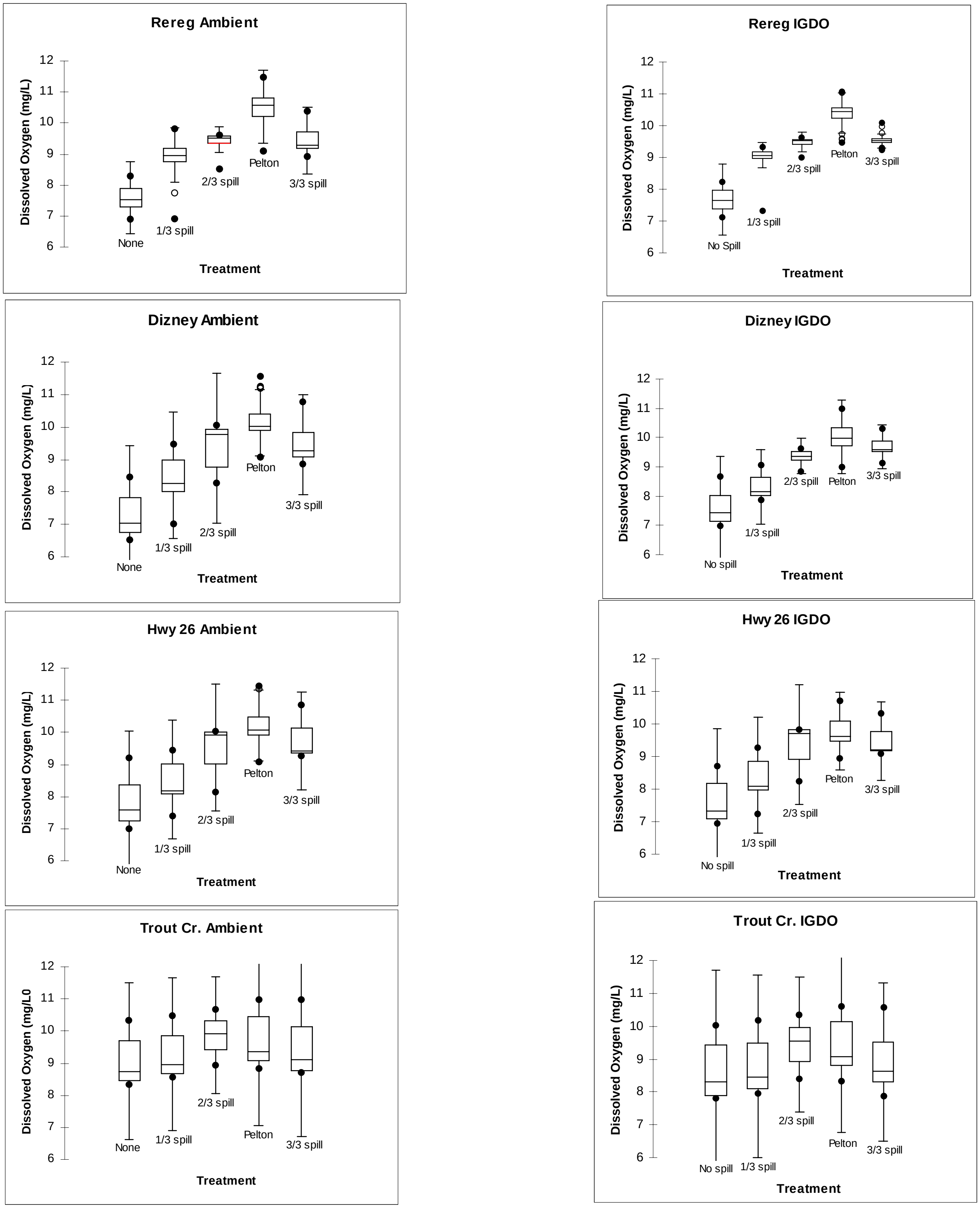


Figure 3. Results of different degrees of spill on dissolved oxygen concentration in the lower Deschutes River.

The 2/3 spill treatment is included in the box plots because there were sufficient data points to include it in this non-parametric method. The 2/3 spill treatment is not included in the statistical calculations because repeated measures ANOVA does not tolerate missing values. Including the 2/3 spill created too many sets with missing values resulting in a severe loss of statistical power.

The incremental effect of increasing the proportion of spill from none to 1/3 spill was greater than that of increasing from 1/3 to full spill at Rereg and Dizney, but not at Hwy 26 or Trout. The mean difference of each increment of spill at each location is summarized in Table 3. The changes in ambient and intergravel DO were similar.

Table 3. The mean increase in ambient DO concentration (mg/L) between incremental increases in the proportion of spill at the Reregulating Dam.

	Location			
	Rereg	**Dizney**	**Hwy 26**	**Trout**
No spill vs 1/3 spill	1.52	1.15	0.80	0.21
1/3 vs. 3/3	0.40	1.04	1.24	0.42

Longitudinal DO Differences

Comparison of Winkler ambient DO between locations revealed a trend of increasing DO with distance from the Reregulating Dam, but no statistically significant difference (P=0.05) between locations Rereg, Dizney, or Hwy 26. However, Trout was significantly different from all three of the other sites. Summary statistics for Winkler DO at each location are provided in Table 4.

Table 4. Summary statistics for Winkler ambient DO (mg/L) measured at four sites in the lower Deschutes River during spill treatments at the Reregulating Dam, September 1999.

	Location			
	Rereg	**Dizney**	**Hwy 26**	**Trout**
Mean	8.86	9.03	9.12	9.62
Standard Deviation	1.12	1.09	1.01	0.76
N	68	68	68	68
Standard error of mean	0.14	0.13	0.12	0.09
Lower 95% confidence interval	8.59	8.77	8.87	9.44
Upper 95% confidence interval	9.13	9.29	9.36	9.81
Minimum	6.40	7.30	7.0	8.2
Median	8.99	8.98	9.18	9.75
Maximum	11.16	11.02	11.16	11.52

The mean differences of corrected ambient DO among all locations, as measured hourly by instruments, were not great (Figure 4). The mean differences between the locations range from 0.1 mg/L DO between Rereg and Hwy 26 to 0.5 mg/L between Dizney and Trout. These differences are less than the ODEQ standards for data quality level A used for field instruments (L. Caton, ODEQ analytical laboratory, personal communication) and are not statistically significant with the exception of Dizney, which was slightly lower than the other three locations.

Water Quality Criteria

The median intergravel DO concentration at all sites was greater than 6 mg/L for the duration of the study, including the period when no water was spilled (Figure 3). Therefore, under normal Project operations, the current ODEQ minimum standard for intergravel DO is met. The current standard for ambient surface water, however, is not met. The ambient DO standard for protection of salmonid spawning is 11.0 mg/L

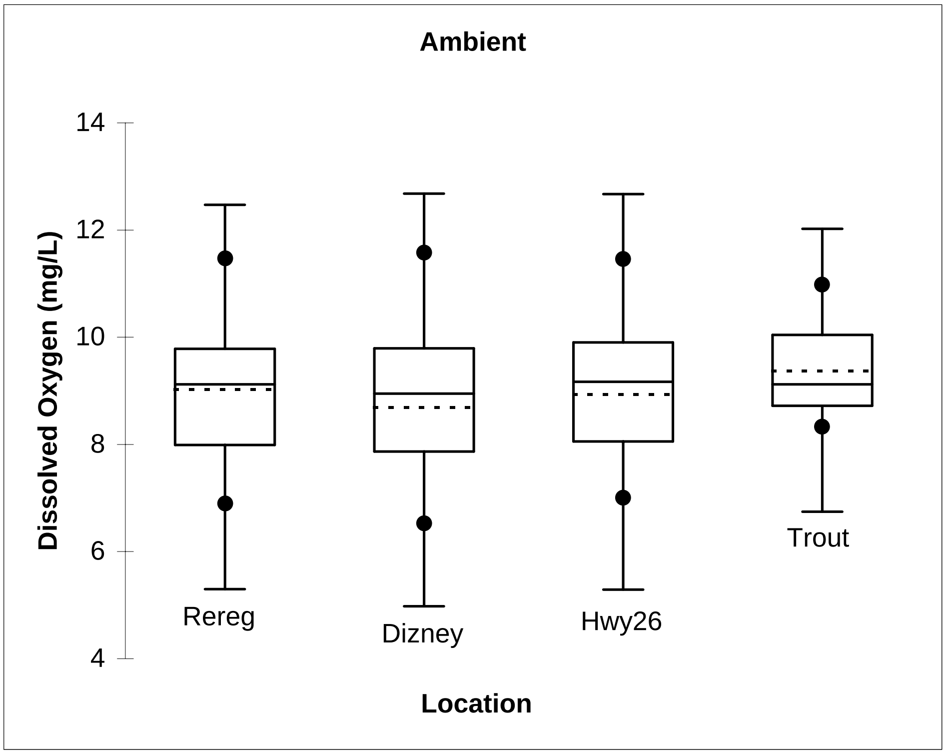


Figure 4. Box plot of ambient dissolved oxygen concentration measured at four locations in the lower Deschutes River in September 1999. The top and bottom of the box correspond to the 75th and 25th percentiles respectively, the solid line through the box marks the median, the dashed line marks the mean, solid circles mark the maximum and minimum, and the whiskers extend 1.5 times the interquartile difference above and below the box.

but can be lowered to 9.0 mg/L if the intergravel DO is 8.0 mg/L or greater. The 1/3 spill increased intergravel DO concentration at all locations above 8.0 mg/L. Because, during this study, there was little or no difference between the ambient and intergravel DO concentration, it is possible to exceed 8.0 mg/L intergravel DO but still not meet the minimum ambient surface water standard of 9.0 mg/L. At Rereg, the 2/3 and 3/3 spills increased the minimum DO to 8.51 mg/L and 8.93 mg/L, respectively, which would still be below the 9.0 mg/L standard. Mean DO levels at the different sites are listed in Table 5.

Table 5. Mean DO concentrations (mg/L) during a 48-hour period at four locations in the lower Deschutes River under various proportions of spill at the Reregulating Dam.

	Rereg		Dizney		Hwy 26		Trout	
	Ambient	IGDO	Ambient	IGDO	Ambient	IGDO	Ambient	IGDO
No spill	7.6	7.7	7.3	7.6	7.8	7.6	9.1	8.6
1/3 spill	8.9	9.0	8.4	8.3	8.5	8.4	9.3	8.8
3/3 spill	9.4	9.5	9.5	9.7	9.7	9.5	9.5	8.9

Diel Cycles

The concentration of ambient DO varies naturally with time of day. During September at the locations used in this study, ambient DO concentration reached a minimum value between 7:00 and 8:00 AM. Concentrations increased through the morning and early afternoon, reaching a maximum value at approximately 2:00 to 3:00 PM. Concentrations then declined rapidly until midnight and more slowly from midnight until just after sunrise, when the cycle repeats. This cycle can be clearly seen in Figure 5.

The various proportions of spill at the Reregulating Dam increased the overall concentration of ambient DO but did not change the pattern or magnitude of the diurnal cycle (Figure 5). Changes in DO concentration were more irregular at Rereg and Dizney. By the time the water reaches RM 87 (Trout) there is little evidence of the changes taking place at RM 100.

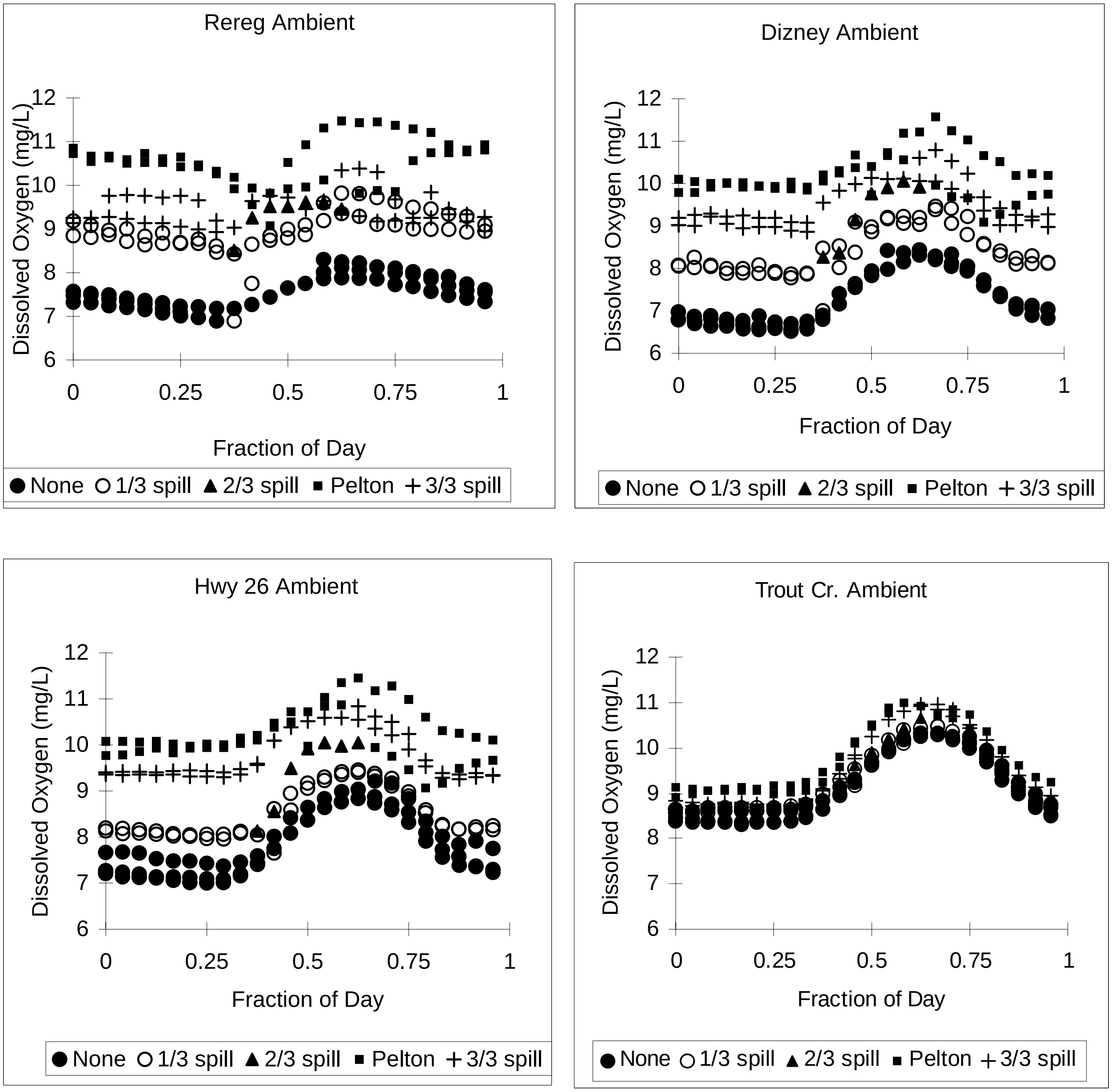


Figure 5. Diurnal cycle of dissolved oxygen in the lower Deschutes River showing the effect of various proportions of spill at the Reregulating Dam.

SUMMARY AND CONCLUSIONS

Water leaving the Project through the turbine at the Reregulating Dam is undersaturated with DO during part of the year, especially in the late summer (September).

For this study, water was spilled from the Reregulating Dam in various proportions of the total flow: no spill, 1/3 spill, 2/3 spill, and full spill. The DO concentration was measured in the ambient water and in the water flowing through the gravel of the river bed to determine the effect of aeration on ambient and intergravel DO concentration. The findings from the study are as follows:

- There was little or no difference in measured DO concentration between the ambient water and intergravel water.
- The median intergravel DO concentration at all sites was greater than 6 mg/L for the period when no water was spilled. Releasing water through spill at the Reregulating Dam increased the DO content of the water below the Project. Spill of 1/3 the total flow was sufficient to raise the intergravel DO concentration at RM 100 above 8 mg/L, but the minimum ambient DO was still less than less than the 9.0 mg/L standard.
- The effect of spill is not linear; the increase from no spill to 1/3 spill had more of an effect on DO concentration (average 11 percent increase) than did the increase from 1/3 spill to full spill (average additional 9 percent increase).
- The effect of spill on DO concentration decreased with distance from the Reregulating Dam; there was a total increase at full spill of 23 percent at RM 100, just below the Reregulating Dam, but only 4 percent below Trout Creek (RM 87).

ACKNOWLEDGEMENTS

We would like to thank Ed Hart for allowing access on his land at the Dizney site. Chris Morris of CTWSRO was very helpful in facilitating access on tribal land at the Hwy 26 site. Richard Hass and Ken Buck graciously allowed access on their land at the Trout site. Rich Madden and Garth Wyatt (PGE fisheries technicians) helped construct the artificial redds and install the standpipes. The PGE operators did a tremendous job varying the spill levels and coping with the study during a major power outage due to a range fire.

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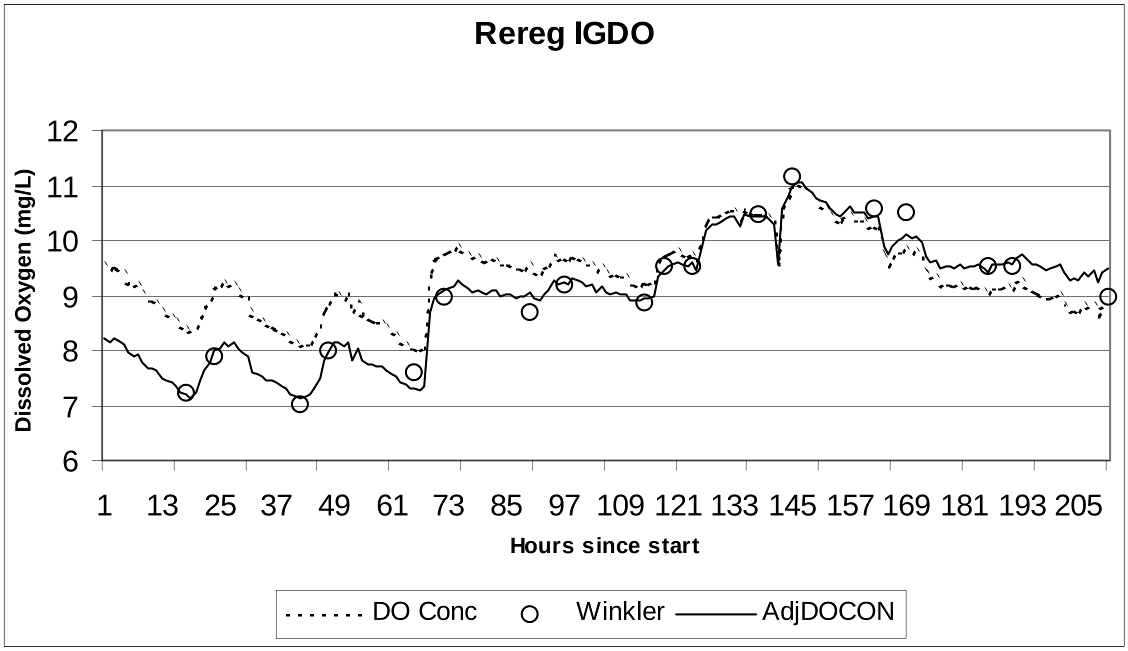
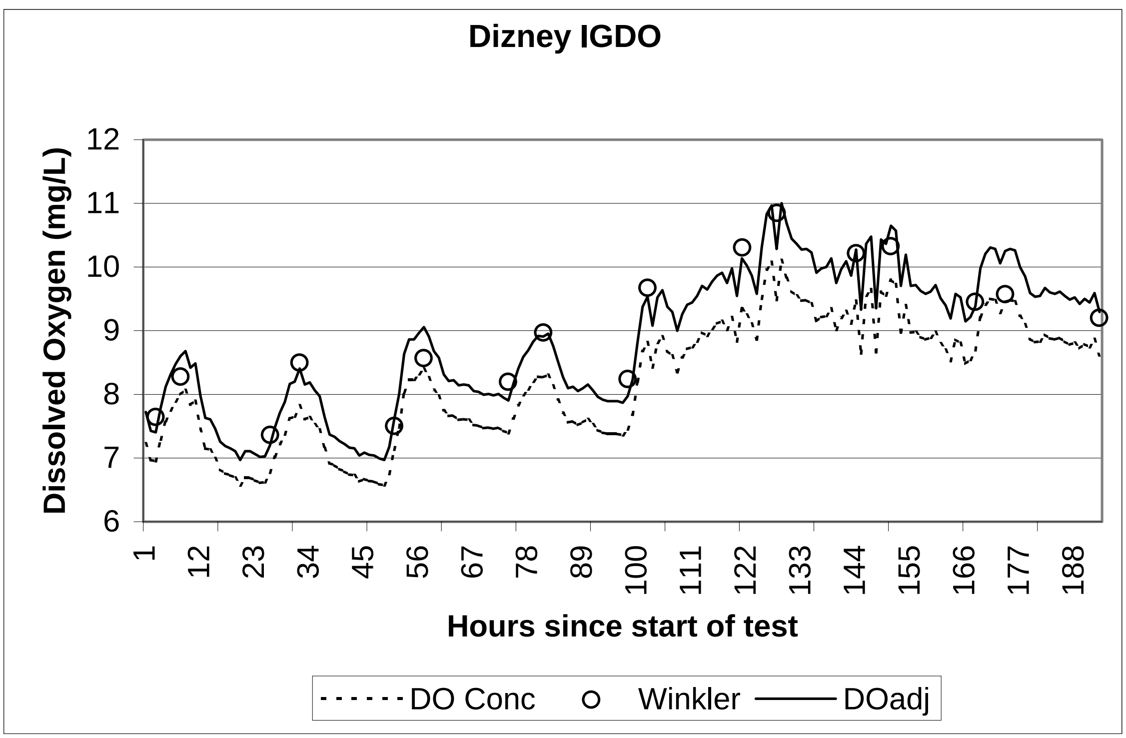
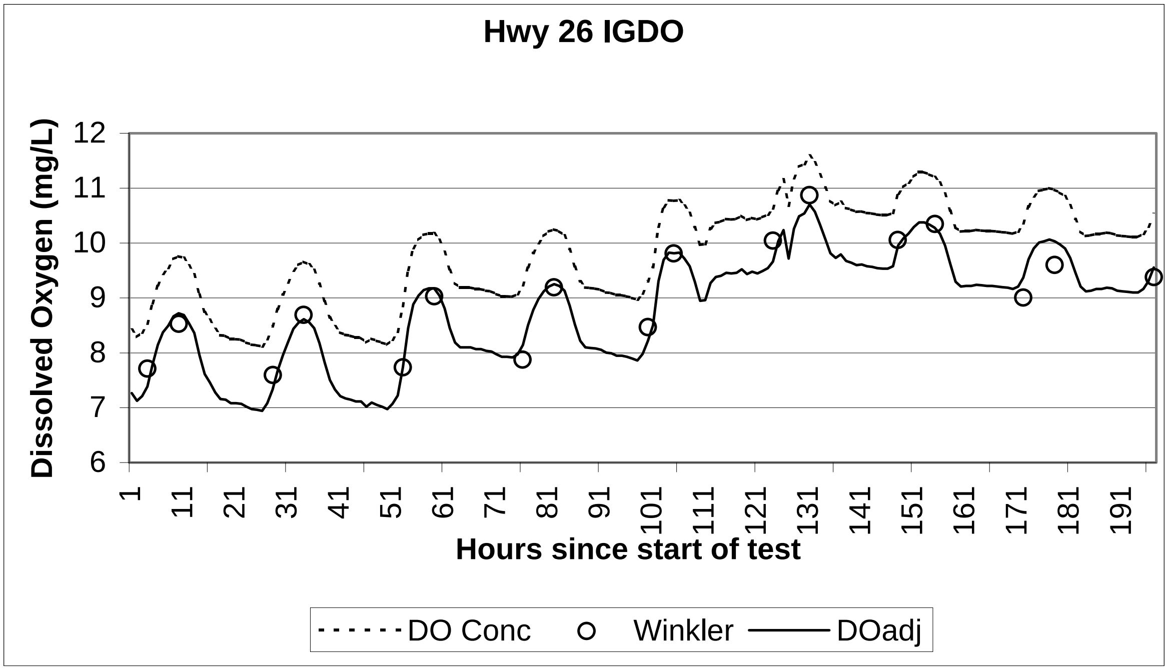
APPENDIX 1

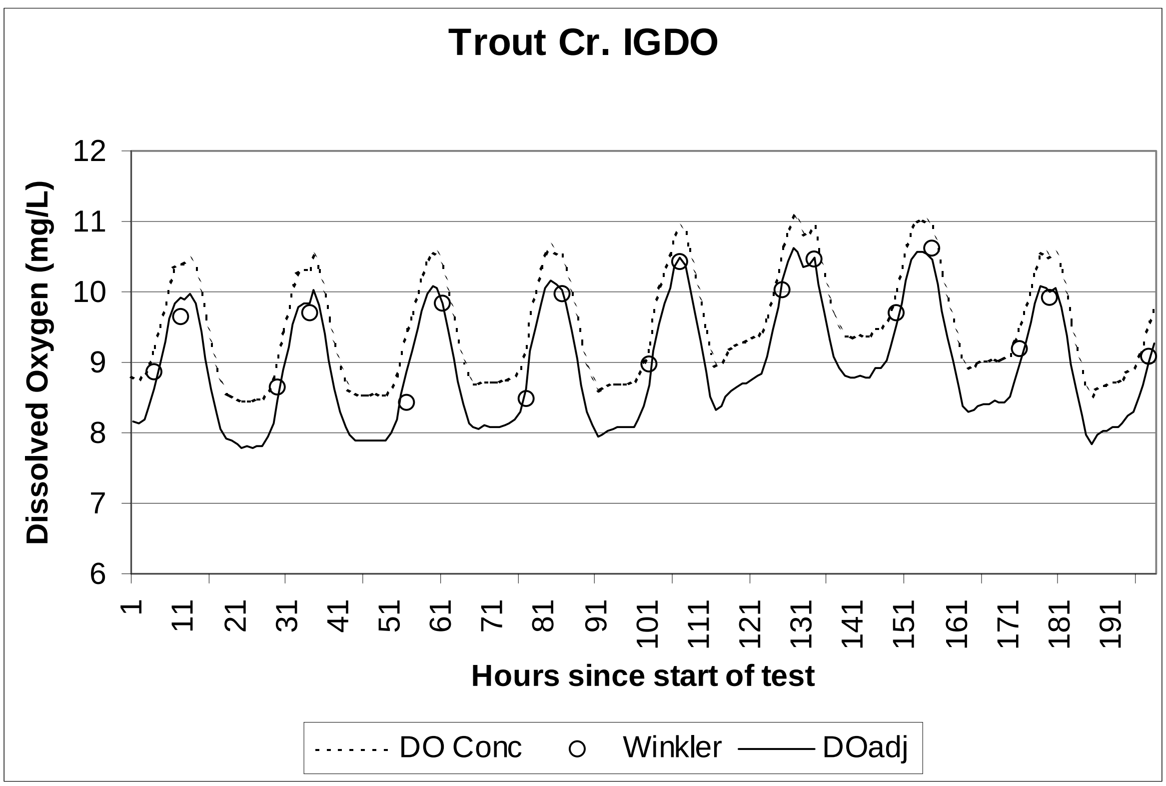
PLOT OF HOURLY MEASUREMENTS OF DISSOLVED OXYGEN





Plot of hourly measurements of dissolved oxygen concentration made at the Rereg and Dizney sites in the lower Deschutes River, September 14-22, 1999. The dotted line shows the raw data, the solid line shows the data normalized to concurrent measurements made by Winkler titration (circles).





Plot of hourly measurements of dissolved oxygen concentration made at the Hwy 26 and Trout sites in the lower Deschutes River, September 14-22, 1999. The dotted line shows the raw data, the solid line shows the data normalized to concurrent measurements made by Winkler titration (circles).

APPENDIX 2

SUMMARY STATISTICS OF THE EFFECT OF VARIOUS PROPORTIONS OF SPILL ON AMBIENT WATER DO CONCENTRATION IN THE LOWER DESCHUTES RIVER, SEPTEMBER 1999.

Appendix 2. Summary statistics of the effect of various proportions of spill on ambient surface water DO concentration in the lower Deschutes River, September 1999.

Location: Rereg

Descriptors	All	No spill	1/3 spill	2/3 spill	Pelton	3/3 spill
No. of observations	197	60	48	7	47	42
Missing values	7	7	0	0	0	0
Min	6.90	6.90	6.90	8.51	9.07	8.93
Max	11.47	8.30	9.82	9.62	11.47	10.38
Mean	9.02	7.58	8.95	9.35	10.54	9.43
Standard dev.	1.19	0.36	0.49	0.39	0.53	0.37
Median	9.11	7.53	8.96	9.52	10.59	9.28

Location: Dizney

Descriptors	All	None	1/3 spill	2/3 spill	Pelton	3/3 spill
No. of observations	211	65	48	7	47	44
Missing values	0	0	0	0	0	0
Min	6.53	6.53	7.01	8.27	9.09	8.86
Max	11.57	8.44	9.46	10.06	11.57	10.79
Mean	8.70	7.26	8.41	9.35	10.16	9.46
Standard dev.	1.26	0.62	0.56	0.76	0.51	0.51
Median	8.98	7.04	8.25	9.76	10.02	9.26

Location: Hwy 26

Descriptors	All	None	1/3 spill	2/3 spill	Pelton	3/3 spill
No. of observations	211	65	48	7	47	44
Missing values	0	0	0	0	0	0
Min	7.00	7.00	7.41	8.13	9.07	9.26
Max	11.45	9.21	9.46	10.05	11.45	10.84
Mean	8.94	7.81	8.48	9.45	10.20	9.71
Standard dev.	1.13	0.67	0.55	0.79	0.54	0.50
Median	9.17	7.59	8.19	9.92	10.08	9.43

Location: Trout

Descriptors	All	None	1/3 spill	2/3 spill	Pelton	3/3 spill
No. of observations	211	63	48	7	47	46
Missing values	0	0	0	0	0	0
Min	8.33	8.33	8.56	8.92	8.83	8.69
Max	10.99	10.32	10.48	10.67	10.99	10.97
Mean	9.37	9.07	9.27	9.85	9.71	9.47
Standard dev.	0.76	0.70	0.69	0.64	0.73	0.81
Median	9.12	8.74	8.95	9.93	9.36	9.11

APPENDIX 3

SUMMARY STATISTICS OF THE EFFECT OF VARIOUS PROPORTIONS OF SPILL ON INTERGRAVEL DO CONCENTRATION IN THE LOWER DESCHUTES RIVER, SEPTEMBER 1999

Appendix 3. Summary statistics of the effect of various proportions of spill on intergravel DO concentration in the lower Deschutes River, September 1999.

Location: Rereg

Descriptors	All	No Spill	1/3 spill	2/3 spill	Pelton	3/3 spill
No. of observations	211	67	48	7	47	42
Missing values	0	0	0	0	0	0
Min	7.12	7.12	7.34	8.99	9.46	9.25
Max	11.06	8.22	9.31	9.61	11.06	10.08
Mean	9.01	7.67	9.03	9.44	10.36	9.55
Standard dev.	1.07	0.33	0.28	0.22	0.39	0.18
Median	9.18	7.65	9.06	9.52	10.44	9.53

Location: Dizney

Descriptors	All	No Spill	1/3 spill	2/3 spill	Pelton	3/3 spill
No. of observations	193	51	48	7	47	40
Missing values	0	0	0	0	0	0
Min	6.97	6.97	7.87	8.83	9.00	9.15
Max	11.00	8.68	9.05	9.64	11.00	10.31
Mean	8.85	7.58	8.31	9.33	10.01	9.69
Standard dev.	1.08	0.52	0.37	0.29	0.47	0.33
Median	8.92	7.43	8.16	9.37	9.98	9.59

Location: Hwy 26

Descriptors	All	No Spill	1/3 spill	2/3 spill	Pelton	3/3 spill
No. of observations	197	51	48	7	47	44
Missing values	0	0	0	0	0	0
Min	6.94	6.94	7.22	8.22	8.95	9.10
Max	10.70	8.72	9.25	9.83	10.70	10.34
Mean	8.78	7.61	8.36	9.31	9.76	9.46
Standard dev.	1.00	0.61	0.52	0.68	0.42	0.39
Median	9.12	7.33	8.10	9.70	9.61	9.22

Location: Trout

Descriptors	All	No Spill	1/3 spill	2/3 spill	Pelton	3/3 spill
No. of observations	199	51	48	7	47	46
Missing values	0	0	0	0	0	0
Min	7.80	7.80	7.94	8.38	8.33	7.85
Max	10.61	10.02	10.16	10.35	10.61	10.58
Mean	8.95	8.65	8.80	9.44	9.39	8.91
Standard dev.	0.82	0.80	0.79	0.72	0.73	0.80
Median	8.80	8.31	8.46	9.54	9.09	8.62