BASSLINK INTEGRATED IMPACT ASSESSMENT STATEMENT

POTENTIAL EFFECTS OF CHANGES TO HYDRO POWER GENERATION

APPENDIX 3:

GORDON RIVER WATER QUALITY ASSESSMENT

L. Koehnken[1]

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the renewable energy business

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1. Water Quality Consultant – Technical Advice on Water, 104 Forest Road, West Hobart, Tas 7000.

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1 INTRODUCTION

This report describes the water quality in the Gordon River and Lake Pedder catchments under current conditions, and discusses potential Basslink related impacts. This section focuses on the freshwater water quality of the middle Gordon River (power station to the Franklin River), with water quality issues associated with Macquarie Harbour described in Appendix 26 of this report series – Macquarie Harbour Water Quality Assessment (Koehnken, 2001).

The most common changes to water quality associated with impoundment and flow regulation involve alterations to temperature, dissolved oxygen, dissolved chemical species (nutrients, iron manganese) and turbidity; modification of these parameters occurs during storage, release, and movement through the downstream waterway (Ashby *et al*, 1995; Cushman, 1985; Poff, 1997). Changes to water quality will be affected by the inputs to the impoundment, duration of impoundment, morphology of the reservoir, depth and characteristics of the offtake, climatic conditions and the nature of the downstream environment (Ashby *et al*., 1995; Cushman, 1985; Poff, 1997).

In this report, present water quality conditions are described for the influent tributaries, Lake Gordon and Lake Pedder, and the Gordon River below the Gordon Power Station to the confluence of the Franklin River. Based on this information and the envisaged additional hydrologic changes proposed for the system under Basslink, potential changes to water quality conditions are presented and discussed, including possible mitigation measures where applicable.

2 METHODOLOGY

The information presented in this report reflects a combination of existing published historical information augmented by recent water quality monitoring. Hydro Tasmania installed a water quality monitoring site in the tailrace of the Gordon power station in July 1999 that records temperature, dissolved oxygen, pH, conductivity and water level. The available record is intermittent due to equipment failures. For the Gordon Basslink investigations, additional level and temperature recorders were installed in the Gordon River 1.5 km below the tailrace (Site 75) and 0.5 km downstream of the confluence of the Gordon and Denison River (Site 62). Two water quality surveys were conducted in March 2000 corresponding to present power station on and power station off conditions. Additional water quality probes capable of recording temperature, dissolved oxygen, conductivity and pH were deployed in August 2000 during a Basslink simulation experiment, when the power station operated similarly to that expected if the Basslink project proceeds.

3 EXISTING CONDITION

3.1 Influent water to Lake Gordon

Because the Gordon River and Lake Pedder catchments lie almost entirely within the Tasmanian Wilderness Southwest World Heritage Area, it would be expected that the quality of water entering Lake Gordon and Lake Pedder would reflect the natural conditions of the region (Figure 1).

The waters of Southwest Tasmania are known for their clear, brown colour and are frequently described as ‘tea colour’. This colour is the result of high concentrations of dissolved organic matter (DOM) in the water, and the rivers feeding Lake Gordon and Lake Pedder are very rich in these compounds. Concentrations for most rivers entering the lakes are typically about 15 mg/L, with a few rivers containing up to 30 mg/L (Table 1, Bowles, 1998). High DOM bearing waters tend to be acidic, dilute and have low alkalinity. The organic – rich nature of these water bodies makes application of the ANZECC (1992) Guidelines of limited value, as toxicological processes may differ between these organic-rich water, and the more typical organic-poor waters upon which ANZECC (1992) is based.

Table 1 contains a summary of water quality information from rivers entering the lakes in the Gordon system. Also presented are historical summaries of water quality collected from the Huon and Gordon Rivers prior to the creation of the power development.

Variations between the sites can be accounted for by a number of factors. The higher calcium, magnesium and pH values at some of the sites indicate that these waterways contain carbonate rocks that are contributing these constituents to the water. In contrast, the lower pH waters have lower calcium and magnesium values.

Iron and aluminium values in Table 1 are naturally elevated and consistent with other Tasmanian organic-rich West Coast waterways, though high compared to other regions of Australia. Several of the aluminium concentrations documented by Bowles (1998) exceed the recommended ANZECC (1992) water quality guideline for this parameter for the Protection of Aquatic Ecosystems (<5µg/l if the pH is 6.5 or less, and <100 µg/l if the pH is greater than 6.5). The Upper Gordon River on one occasion was more than double the guideline value. It is generally believed, though not directly demonstrated, that the aluminium is complexed by DOM in the waterway, thus reducing its bioavailability (Malcolm, 1985; Koehnken, 1992). Although there is not a simple relationship between DOM and aluminium, it is worth noting that the water sample with the lowest DOM value (Upper Huon R) also recorded the lowest aluminium concentration.

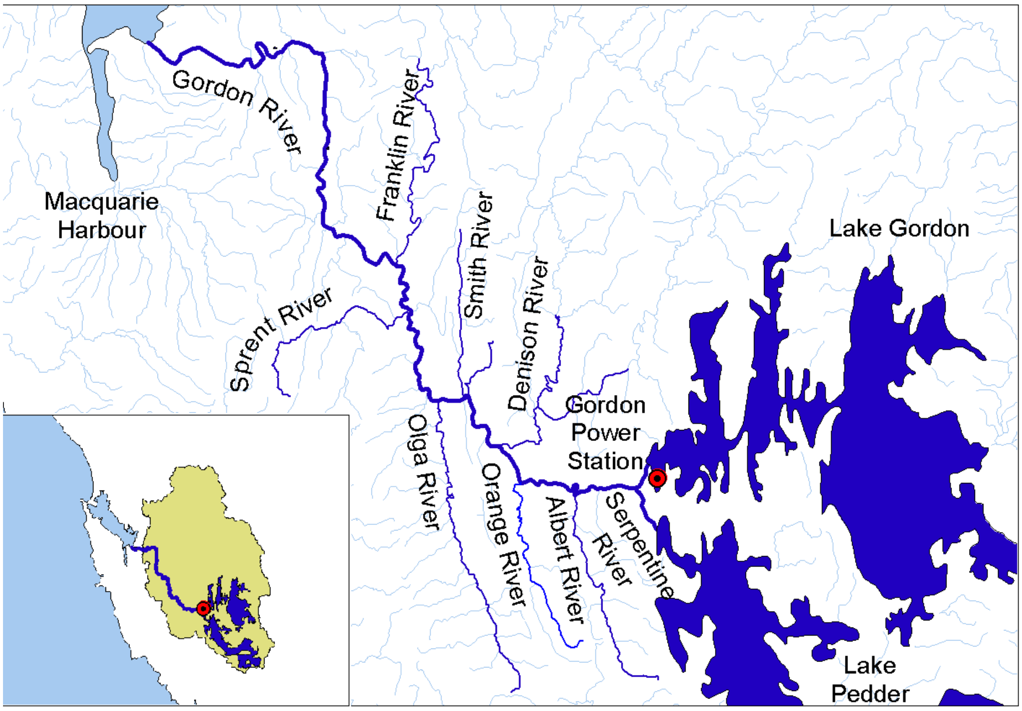


Figure 1. Map of Gordon River catchment showing rivers and lakes.

Overall, the water quality of influent waters to Lake Gordon and Lake Pedder is excellent, and would not be expected to change under Basslink.

Table 1. Water quality results from Bowles, (1998), and historic data from the HEC Hydrol database

Site	Date	pH	Ca	Mg	Fe	Mn	Si	K	Na	Al	DOM
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/
Rivers entering Lake Gordon & Lake Pedder											
Upper Gordon River	15/1/96	7.96	17.7	2.86	0.217	0.005	2.663	0.55	4.59	0.049	
	24/6/96	7.18									17.0
	24/6/96	7.37	6.8	1.28	0.312	0.002	1.78	0.35	3.59	0.204	14.0
	24/2/97	7.19									14.0
	24/2/97	7.19	11.4	2.03	0.336		1.97	0.361	3.18	0.076	17.0
Adam/Eve River	15/1/96		24.2	4.44	0.324	0.021	2.613	0.53	5.74	0.03	
Adam R	24/6/96	7.61	12.3	7.45	0.647	0.010	3.26	0.27	5.56	0.135	27.0
	24/2/97		20.4	7.57	0.661		3.24	0.308	5.24	0.240	
Eve R	24/6/96	7.18	10.8	0.934	0.456	0.006	1.06	0.33	4.51	0.186	25.0
	24/2/97		15.9	1.33	0.353		1.81	0.268	4.19	0.064	
Holley R	24/6/96	5.32	0.715	0.716	0.365	0.009	0.967	0.31	3.31	0.318	15.0
	24/2/97	6.05	1.16	1.05	0.370		1.50	0.227	3.46	0.276	14.0
Pokana R	24/6/96	7.29	3.69	3.20	0.343	0.002	1.42	0.33	3.84	0.167	15.0
	24/2/97	6.87	4.16	3.34	0.509		1.17	0.26	3.20	0.166	17.0
Runoff near Gordon P/S (boat ramp)	24/6/96	4.37									16.0
	24/2/97	4.37	0.252	0.756	0.042		0.273	0.394	4.47	0.151	21.0
Upper Huon River	24/2/97	7.74	19	16.9	0.037		3.92	1.1	5.11	0.023	0.3
Pre-dam water quality											
Huon R @ Scotts Peak (Average)	1967-1970, n=9	6.4	4.8	3.5	0.21	0.01	2.0	0.27	5.0		
Gordon R above Olga (Average)	11/68 n=6	6.2	4.6	2.1	0.21	0.01	1.7	0.2	4.9		

3.2 Lake Gordon and Lake Pedder

There are two primary processes that increase variability in the water quality in Lakes Gordon and Pedder. One is alteration due to impoundment, which includes changes to water quality through internal mixing in the lakes, and seasonal stratification. The other process is dilution due to incident rainfall on the lake surfaces.

3.2.1 Lake stratification

Seasonal stratification of lakes occurs when thermal stratification within a water body results in the denser, cold water layer becoming isolated from the atmosphere for an extended period. During this time, the dissolved oxygen in the lower waters is consumed through the degradation of organic material, frequently associated with bottom sediments. The resulting low oxygen conditions in the bottom water promote the reduction and subsequent release of manganese and iron oxides and hydroxides (and any associated 'scavenged' metals) from sediments into the water column. Following the creation of a new impoundment, this process typically results in very low, or no oxygen conditions near the lake bed due to the large mass of organic material available for degradation. This initially very high oxygen demand reduces over a number of seasons as the organic material decays.

Deoxygenated water in an impoundment leads to an environmental impact if the water is released to the downstream environment. In hydro lakes, this can occur when the level of the intake to the power station is located within the deoxygenated layer of the lake. Low dissolved oxygen concentrations in a waterway can detrimentally affect in-stream biota, and result in nutrient and metal release from sediments (draft ANZECC, 1999).

Seasonal stratification continues until the surface waters cool sufficiently to eliminate the density difference between the warm upper layer and the colder lower layer and mixing occurs.

Figure 2 shows recent temperature and dissolved oxygen profiles for a site near the intake to the power station over an eleven-month period (Hydro, unpublished data). The profiles indicate that variations in dissolved oxygen concentrations have occurred over approximately 60 to 70 m of the water column. Below this depth, which coincides with a localised hollow on the lake bed, low dissolved oxygen water is present year round, indicating limited mixing of this water.

In Lake Gordon, Steane and Tyler (1982) observed stratification within the lake soon after creation of the reservoir in the late 70s. An interesting observation made by the pair was that during the colder months, the incoming (well oxygenated) Gordon River water follows its old course, and 'flows' at a depth determined by density beneath the less oxygenated, less-dense waters. This process resulted in the formation of distinct strata within Lake Gordon. Bowles (1998) also identified this under-flow, but found it contained higher concentrations of dissolved oxygen then previously documented. This is interpreted as indicating that much of the originally inundated organic matter has decomposed over the intervening years and the present oxygen demand of the bottom waters is lower than immediately following inundation.

3.2.1.1 Impacts of stratification and lake level on temperature and dissolved oxygen of water currently released from the power station

The temperature and dissolved oxygen profiles in Figure 2 also indicate the location of the base of the intake opening to the Gordon Power Station. Because the operating range of Lake Gordon can fluctuate by approximately 40 m, the relative position of the intake with respect to the surface of the lake will vary by this amount. Figure 3 demonstrates that during periods of very high lake level, the intake will be positioned relatively low in the water column with respect to the lake surface level. Conversely, the intake will occupy a much higher position in the water column relative to the lake surface when lake level is very low. These fluctuations in lake level in combination with the seasonal stratification of the water body will control the temperature and dissolved oxygen concentration of the water entering, and eventually exiting the power station.

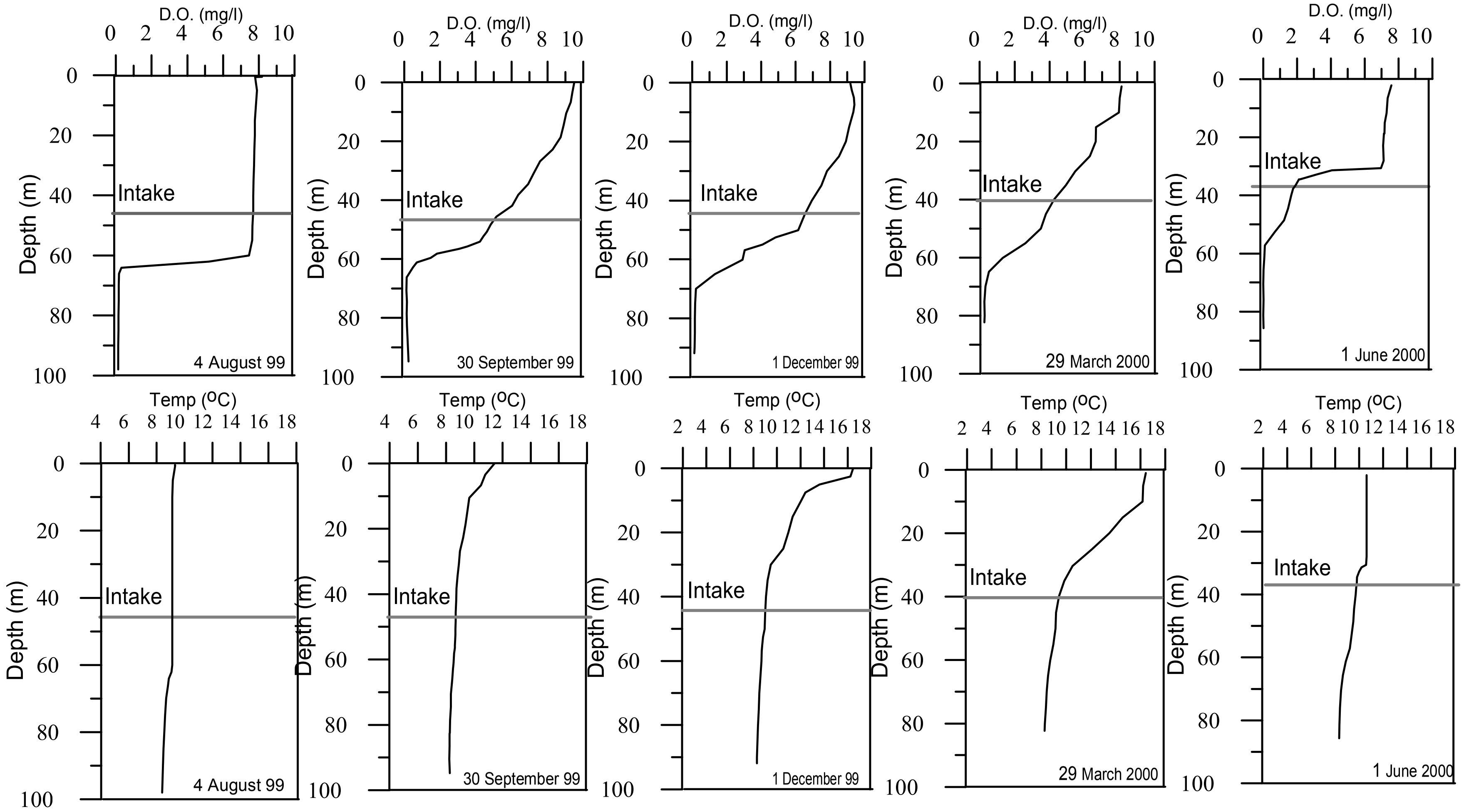


Figure 2. Dissolved oxygen and temperature profile obtained from Lake Gordon in basin near power station intake (Hydro, unpublished data).

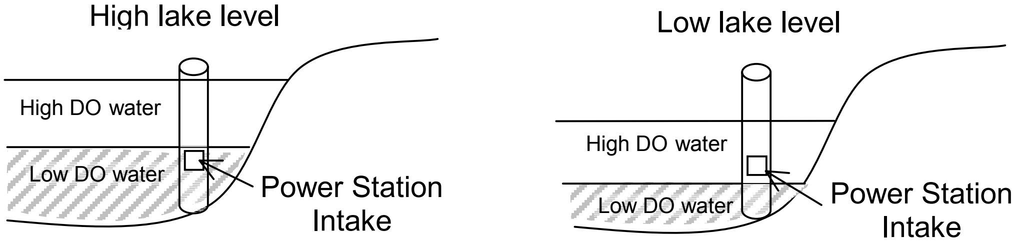


Figure 3. Schematic diagram demonstrating effect of lake level on relative position of power station intake

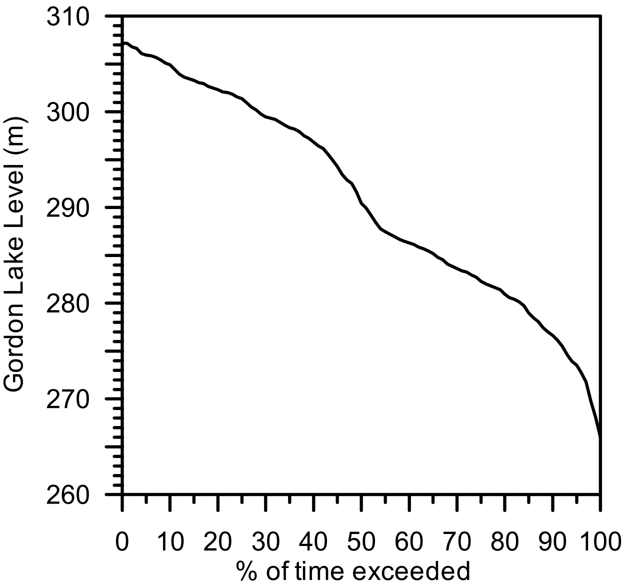
During the winter period (eg August 99), when the water column at and above the power station intake is relatively uniform with respect to temperature and dissolved oxygen, the water drawn into the power station is similar to surface water in the lake, or nearby tributaries. Dissolved oxygen concentrations are well in excess of the recommended 6 mg/l for protection of aquatic ecosystems (ANZECC, 1992), and temperatures are in the common winter range of 6 – 10 °C for West Coast rivers (Koehnken, 1992).

There is greater variation between surface waters and water at the power station intake during the summer season. Typically, the water entering the power station is cooler than the tributaries by approximately 3 – 10 °C, assuming a lake temperature of 9°C and comparing with 12 – 19 °C found in other West Coast rivers (Koehnken, 1992; DPIWE, unpublished data). The propagation of this water downstream is discussed in the next section.

During the summer months, there is also a greater risk of discharging water containing low concentrations of dissolved oxygen, with concentrations at the intake decreasing to 5 mg/l during the summer of 2000, less than the ANZECC 1992 Guideline of 6 mg/L. If lake level were significantly higher, lower dissolved oxygen water would be discharged, as the intake would be relatively lower in the water column profile.

Based on the water column profile for March 2000 in Figure 2, dissolved oxygen concentrations are reduced to less than 6 mg/L at a depth of 35 m to 40 m under summer conditions. The intake will coincide with these depths (35 – 40 m) when lake levels exceed 290 – 295 m. A lake level duration curve for Lake Gordon is shown in Figure 4, and indicates that lake levels of 295 m and 290 m are exceeded 45% and 50% of the time, respectively. A time-series plot of lake level in Lake Gordon (Figure 5) shows that these lake levels have been exceeded during 2 periods; one corresponding with the first five years of operation of the station, and the second occurring during the mid to late 1990s.

Figure 4. Water level duration curve for Lake Gordon, 1976 - 1999



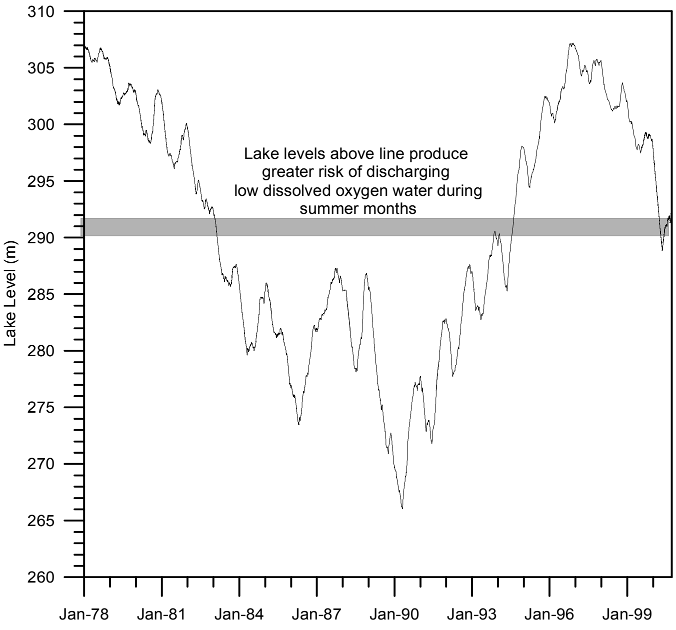


Figure 5. Water level in Lake Gordon between Jan 1978 and Jan 2000.

Line indicates lake level above which depth of intake exceeds 35 m and risk of discharging low dissolved oxygen water is increased in summer

During the first period of high lake level, strong anoxic conditions related to the decay of the recently inundated organic material combined with very high lake levels lead to the release of deoxygenated water from the power station (Steane and Tyler, 1982). Recent monitoring of dissolved oxygen at the tailrace of the power station began in May 1999 and continues to the present, reflecting lake levels of between 289 m and 299 m (Figure 6). The 99/00 summer period along with Lake Gordon water level is shown in greater detail in Figure 7. The 'spiking' of the data in both Figures 6 and 7 is attributable to the use of 'air-injection' in the power station, and is associated with improving the efficiency of the turbines under intermediate power load conditions. The lowest dissolved oxygen values recorded at the tailrace at any time represent the dissolved oxygen concentrations in the water when air injection is not in use. Air injection is discussed in the next section.

The year-long dissolved oxygen record (Figure 6) depicts winter concentrations of 8 – 9 mg/L, decreasing to below 5 mg/L during the summer months when air injection is not in use. Air injection increases these concentrations by between 2 mg/L and 6mg/L.

Water level in Lake Gordon (Figure 6) decreased by approximately 10 m between December 1999 and May 2000 from about 300 m to 290 m, corresponding to the period of decreasing dissolved oxygen concentrations at the tailrace. If lake level had remained 10 m higher (300 m) during the summer, the intake would have drawn water from 10 m deeper in the profile, and dissolved oxygen concentrations at the tailrace would have been about 3 mg/L in March based on the water column profile in Figure 2. In June, the 6 m intake 'straddles' a sharp decrease in dissolve oxygen values producing higher values than during the summer at the tailrace (Figure 6). Lake levels 10 m higher during June would have resulted in the intake of water containing <2mg/l in to the power station. The propagation of this water downstream in the Gordon River is discussed in Section 3.3.

3.2.1.2 Impact of air injection on water released from the power station

Air injection is a management tool used in the operation of the power station to increase the efficiency of individual turbines under intermediate power loads. The use of air injection in the power station increases the dissolved oxygen concentrations in the discharge water by 2 to 6 mg/L. Figures 8 and 9 show dissolved oxygen concentrations at the tailrace for a winter and summer period, and include the energy output for the individual turbines in the Gordon Power Station during the same period. The graphs show that when the energy output of any of the turbines is less than about 110 MW, air injection is utilised, resulting in an increase in dissolved oxygen concentrations. Larger dissolved oxygen increases result when two or more turbines require air injection at the same time. These spikes are superimposed on a wintertime 'baseline' dissolved oxygen concentration of about 9 mg/L and a summer baseline of 5 to 6 mg/L.

During periods when the Gordon Power station is used extensively at these intermediate power loads, such as winter, air injection is in frequent use and air-injection 'on' conditions dominate the dissolved oxygen regime at the tailrace (Figure 6, winter). Conversely, during the summer months, when the Gordon Power station is used predominantly under maximum power generating conditions, which do not require air injection, the dissolved oxygen concentrations reflect conditions in Lake Gordon (Figure 6, summer).

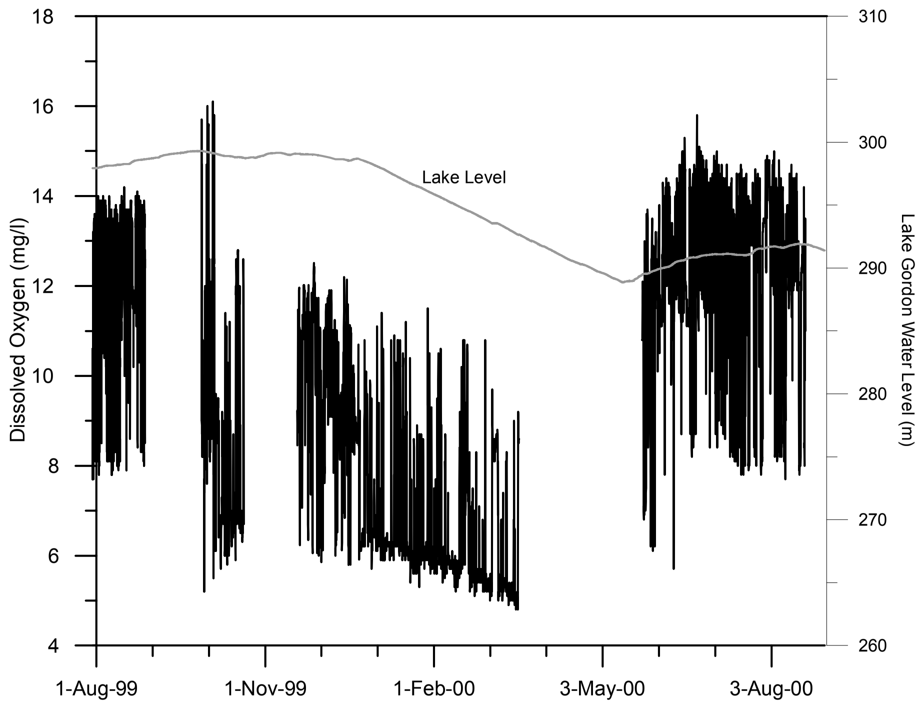


Figure 6. Dissolved oxygen concentrations at the tailrace of Gordon Power Station between Aug 99 and Aug 00. Spikes in data are due to power station shutdowns and air injection (Hydro Tasmania, unpublished data). Lake level of Lake Gordon also shown.

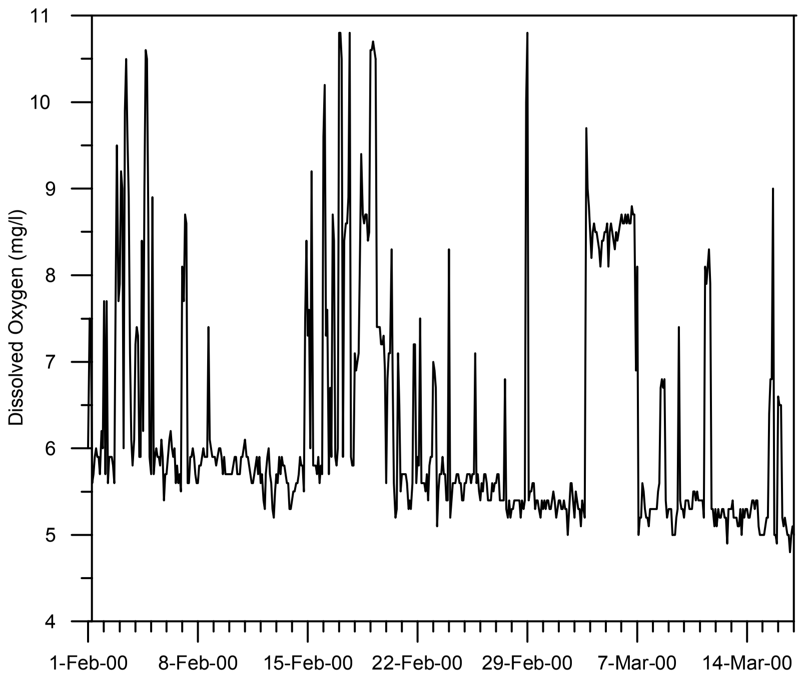


Figure 7. Dissolved oxygen concentrations at tailrace of Gordon Power Station during summer 2000. Spikes indicate the use of air injection in the power station (Hydro Tasmania, unpublished data).

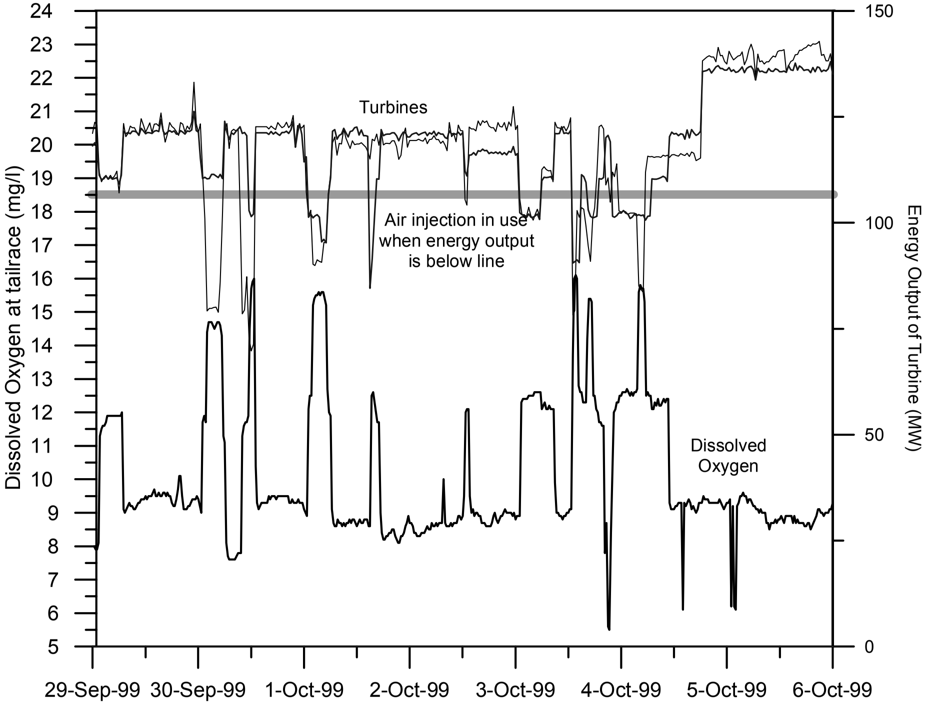


Figure 8. Dissolved oxygen concentrations at tailrace and energy output of turbines in the Gordon Power Station at end of winter 1999. Only two turbines were in use during this period. Air injection used when energy output falls below line.

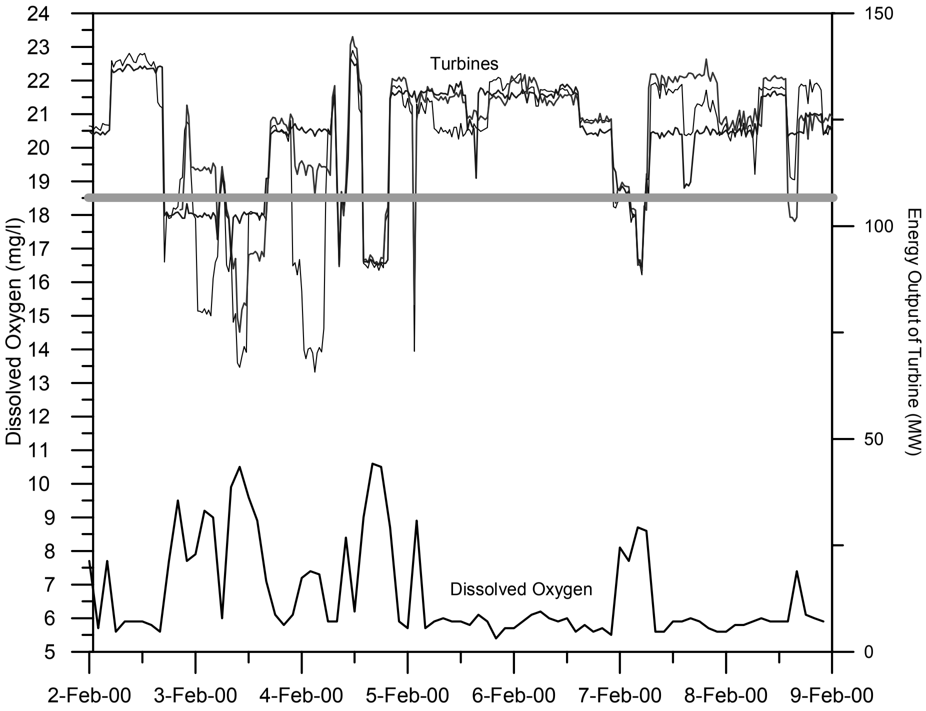


Figure 9. Dissolved oxygen concentrations at tailrace and energy output of turbines in Gordon Power Station during February 2000. Three turbines were in use during this period.

3.2.1.3 Impact of lake stratification on composition of water in Lake Gordon

Bowles (1998) obtained chemical profiles of Lake Gordon during summer and winter periods that demonstrate a gradual increase in iron and manganese concentrations with depth in the lake, undoubtedly related to the changing dissolved oxygen conditions. Table 2 contains iron and manganese concentrations from water column profiles obtained in January 1996, and June 1996, and from the tailrace below the power station at the same time.

Table 2. Iron and manganese concentrations in Lake Gordon and at the tailrace of the power station

	January 1996			June 1996	
Depth	**Iron (mg/l)**	**Manganese (mg/l)**	**Depth**	**Iron (mg/l)**	**Manganese (mg/l)**
Surface	0.22	0.003	Surface	0.28	0.004
20 m	0.25	0.004	15 m	0.26	0.002
50 m	0.27	0.004	35 m	0.29	0.005
70 m	0.31	0.006	50 m	0.39	0.013
90 m	0.41	0.014	60 m	0.47	0.012
			70 m	0.69	0.029
			100 m	1.09	0.055
Depth of intake ≈55 m			Depth of Intake ≈55 m		0.063
Tailrace	0.38	0.007	**Tailrace**	0.44	0.015

In spite of the increase with depth of the metals, the concentrations discharged from the power station are low and similar to metal concentrations of influent rivers (Table 1) and would not pose an environmental risk. The reason the surface values are much lower than the deeper values is because considerable dilution occurs within the lake, due to incident rainfall (Bowles, 1998). Water collected at the tailrace is similar in composition to the lake depth at which the water is drawn, and indicates that little or no changes to metal concentrations occur within the power station.

Table 3 contains additional water quality information from the same profiles in Lake Gordon (Bowles, 1998). The data demonstrate that there is very little variation in these parameters with depth in the lake, and when compared to Table 1, also demonstrate the high dilution occurring in the lakes.

Table 3. Composition of Lake Gordon water with depth

Depth	Date	pH	Ca mg/l	Mg mg/l	Si mg/l	K mg/l	Na mg/l	Al mg/l	DOM mg/
Surface	1/96	6.8	1.24	0.954	0.638	0.37	4.64	0.110	
20	1/96		1.27	0.946	0.664	0.39	4.43	0.107	
50	1/96	6.4	1.29	0.954	0.694	0.37	4.43	0.114	
80	1/96	6.5	1.22	0.923	0.666	0.39	4.44	0.120	
Surface	6/96	5.9	1.27	0.942	0.649	0.40	4.41	0.111	7.1
15	6/96	6.0	1.26	0.937	0.634	0.41	4.36	0.101	7.0
35	6/96	6.4	1.26	0.939	0.642	0.41	4.36	0.108	6.7
50	6/96	5.8	1.28	0.936	0.657	.036	4.38	0.118	6.7
60	6/96	5.6	1.32	0.949	0.674	0.40	4.36	0.121	6.2
70	6/96	6.3	1.31	0.944	0.680	0.37	4.27	0.121	6.0
85	6/96	6.2	1.32	0.949	0.695	0.33	4.38	0.130	6.7
100	6/96	6.0	1.34	0.958	0.697	0.41	4.37	0.145	7.1

Dilution through direct precipitation is high in Lake Gordon and Lake Pedder because the lakes occupy a large portion of the total catchment area. Bowles (1998) estimated that approximately 45% of Lake Pedder's volume, and 17% of Lake Gordon's volume is contributed by direct precipitation. These observations do not hold for sodium (Na) because its major source is precipitation in the Gordon catchment, resulting in similar values for the influent and resident waters of Lake Gordon.

Water quality monitoring conducted by the IFC in 1993 – 1994 and 1996 – 1997 recorded low concentrations of nutrients and overall low productivity in Lake Gordon and Pedder. Because of the lack of development in the region, and the low natural concentrations of nutrient in the waters, algal or nutrient water quality issues are not considered to be an issue in the Gordon or Pedder catchments.

3.3 Gordon River below the power station

3.3.1 Introduction

Below the Gordon Power station, the water quality of the river is controlled by the relative inputs of water derived from Lake Gordon via the power station, the entering tributaries, and ambient conditions. Little historical information exists pertaining to the water quality of the middle Gordon River due to access constraints. The following discussion is largely based on the results of the recently conducted water quality surveys and *in situ* probes. The March 2000 water quality survey was conducted during an extended dry period, when tributaries were at a summer base flow. Results (Table 4) should reflect a strong groundwater component, and are probably higher than mean annual values, as winter rains generally dilute groundwater inputs. At the time of sampling, Gordon Lake level was 293 m, resulting in an intake level of about 42 m below the water surface. The dissolved oxygen concentration and temperature at the intake was about 4 - 5 mg/L and 9 °C, respectively (Figure 2). During the power station 'On' sampling run, three turbines were in use at maximum discharge without air injection.

3.3.2 Composition of water & conductivity

Comparing Tables 3 and 4 shows that the Lake Gordon derived water and the tributary waters differ in chemical parameters such as pH, calcium, magnesium, alkalinity, DOC and conductivity. This is due to the widespread presence of limestone in the tributary catchments compounded by significant dilution of these parameters in Lake Gordon by rainfall. Thus, parameters such as alkalinity, calcium and magnesium, which have a predominantly limestone source can be used as 'tracers' for these waters.

Table 4 demonstrates that when the power station is operating, the water quality of the river is dominated by low alkalinity, low calcium and magnesium water, reflecting Lake Gordon conditions. Conversely, when the power station is off, the water quality in the Gordon more closely resembles tributary inputs. The results also demonstrate that sulphate is low throughout the catchment, and sodium and chloride values are highest in the tributary catchments located closest to the coast, reflecting marine aerosols derived from the westerly airstream.

Conductivity can be used as an indicator of water provenance in the middle Gordon River due to the lower ionic strength of the Lake Gordon derived water. Figure 10 shows conductivity values for the Gordon River above the Splits, reflecting the input of the power station, small creeks and the Albert River, and below the confluence of the Denison River, a major tributary. Discharge from the power station tailrace is also shown, with operation of the station fluctuating between maximum discharge and off for most of the time period shown. The last two days of the time-series reflect the power station alternating between three turbine and two turbine operations. The time required for the water to travel from the tailrace to the downstream sites results in a small time delay between changes to power station discharge and conductivity response, as shown in the plots. Conductivity peaks correspond to power station off conditions.

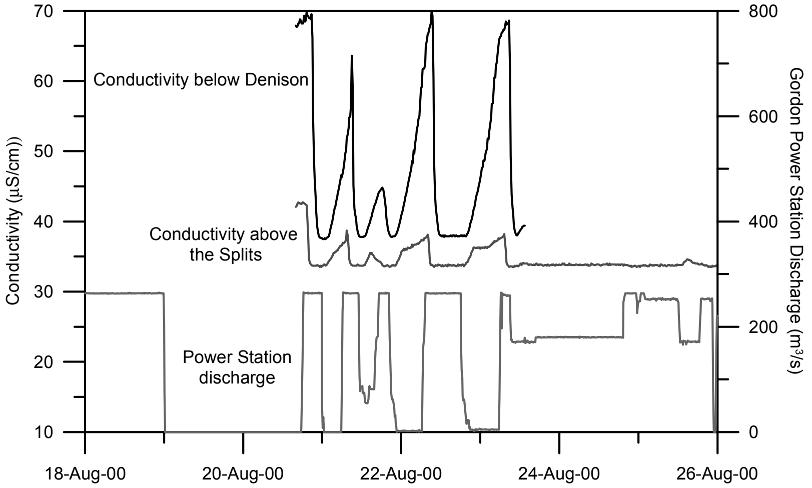


Figure 10. Conductivity values (µS/cm) in the Gordon River above the Splits and Gordon River below the Denison River during fluctuating power station operating conditions.

The data show that when the power station is operating conductivity values are low, reflecting the input of water from Lake Gordon. During periods of power station shutdown, conductivity values increase slightly above the Splits, and display a large increase below the confluence of the Denison River. A partial decrease in discharge from the power station, for example during the 21st of August when the station decreased discharge to about 100 m^3/s (one turbine operating), resulted in intermediate values at the downstream sites. The asymmetry of the conductivity peaks, a gradual increase and rapid decline, suggests that when the power station shuts down, water derived from the tributaries gradually increases in contribution to the flow, resulting in a slow rise in conductivity. When the power station initiates operations, the rapid decrease in conductivity indicates that the power station derived flow very rapidly dominates the total flow.

Although discernible and useful as a means of tracking water masses in the Gordon River, the magnitude of conductivity and chemical fluctuations shown by the data is not an issue in terms of aquatic health, as both power station off and on conditions result in low ionic strength water present in the middle Gordon River.

3.3.3 Dissolved oxygen

The dissolved oxygen results from the March 17th water quality survey (Table 4) show that concentrations increased from about 5 mg/L in the lake (Figure 2) to about 6 mg/L by the time this water entered the river from the 1.6 km tailrace tunnel. This increase was not associated with air injection, and is probably attributable to the turbulent flow in the tailrace tunnel. The field data indicate that dissolved oxygen concentrations continued to increase rapidly with distance downstream of the power station, with ambient conditions re-established within about 1.5 km of the tailrace. The oxygenation of the river water is undoubtedly promoted by the turbulent flow present in the first few kilometres below the power station. This reach is bedrock controlled, has a steep slope and almost continuous rapids.

Figure 11 shows dissolved oxygen concentrations at the tailrace of the power station, in the Gordon River above the Splits and in the Gordon River below the Denison River during August 2000. Discharge from the power station is also shown. The travel time required for the water to flow downstream results in a lag of dissolved oxygen values at the above Splits and below Denison sites compared to power station operation, with peaks in dissolved oxygen corresponding to power station on conditions (data in Figure 11 is not corrected for lag time). Dissolved oxygen concentrations at the tailrace directly correspond to water levels at the same site. Although the dissolved oxygen probe at the tailrace malfunctioned during August 21st, the first three days provides an indication of the dissolved oxygen levels associated with power station operation.

Based on Figure 11, water released from the power station contained oxygen concentrations of about 8 mg/L. These concentrations increased to about 12 to 13 mg/L at the downstream sites, similar to the values recorded during the March water quality survey, when initial tailrace concentrations were 5 mg/L. In the Gordon River above the Splits and below the Denison, dissolved oxygen concentrations were higher during periods of power station operation than during shut-downs, in spite of the relatively low dissolved oxygen concentrations present in the power station discharge and the dominance of this water in the river. This suggests that the higher flow velocity and turbulence in the river that accompanies power station operation controls the dissolved oxygen concentrations in the river to a greater degree than the conditions in Lake Gordon. The equilibration with ambient conditions appears to occur within about 1.5 km downstream of the tailrace (Table 4).

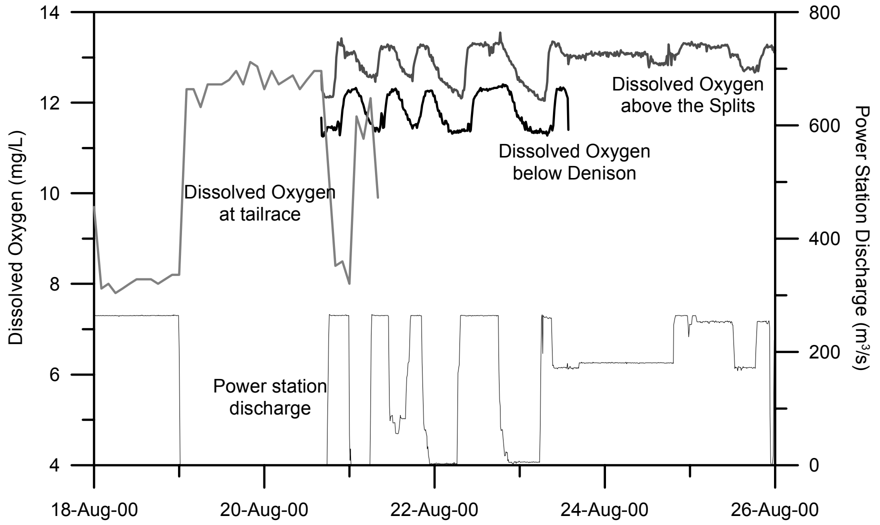


Figure 11. Dissolved oxygen concentrations at the tailrace, in the Gordon River above the Splits and Gordon River below the Denison River during fluctuating power station operating conditions.

The draft ANZECC (1999) guideline for dissolved oxygen for freshwater fish is > 6 mg/L. The results of the water quality surveys demonstrate that this value is obtained at the end of the tailrace tunnel even when dissolved oxygen concentrations in the water entering the power station are below this value. The data also clearly show there is a very large increase in dissolved oxygen concentration within short distances downstream of the tailrace due to the turbulent nature of the river during power station operation.

Figure 12 shows the dissolved oxygen data from the Gordon River above the Splits and below the Denison River plotted as a function of oxygen saturation in water, showing the water is supersaturated with respect to this gas at the upstream site. The results in Table 4 indicate dissolved oxygen values increase between the power station and Snake Rapids, the steepest part of the river, and then decrease downstream.

The supersaturation of gases in water for extended periods can lead to gas bubble disease in fish. Gas bubble disease is the physically induced process caused by uncompensated high total dissolved gas pressure, which produce lesions in blood and tissues and leads to physiological dysfunctions (Brouck, 1980). The condition has been observed when *total* gas pressure in a water body exceeds 105% of atmospheric pressure. Of this total, dissolved oxygen contributes only a small part because nitrogen is the major component of air (78%). Dissolved oxygen concentrations of up to 250% are tolerable by fish if no other gases are increased (Svoboda *et al*., 1993). ANZECC (1999) provides a guideline value of 105% Total Gas Pressure for the protection of aquatic species.

The supersaturation of gases in water has been observed downstream of power stations and in natural ‘plunge’ pools below water falls (Weitkamp and Katz, 1980; Sanger, 1992). The Inland Fisheries Commission in Tasmania developed guidelines for the operation of the Reece Power Station in Western Tasmania, after a combination of air entrainment as water entered the shallow level intake, and the subsequent use of air injection in the power station, resulted in a fish kill in the Pieman River in 1990 (Sanger, 1992).

Because the increase in oxygen saturation in the Gordon River is due to the uptake of air during turbulent flow in the river, it is possible that total gas pressure is also increased, although to what extent is not known. It is also unknown what effect air injection in the power station has on the downstream dissolved oxygen concentrations. The Basslink instream biota investigations (Appendix 8 of this report series – Gordon River Fish Assessment (Howland *et al*, 2001)) have not observed any symptoms of gas bubble disease on individual fish sampled from the middle Gordon River, and catch rates do not reflect dissolved oxygen trends (M. Howland, pers. com.). Previous studies have found that rapids with deep plunge basins downstream of rapids tend to increase gas saturation to undesirable levels, whereas rapids ending in shallow pools do not (Lindbroth, 1957). The general morphology of the middle Gordon River falls into the later category. This issue is further discussed under 'Management Issues'.

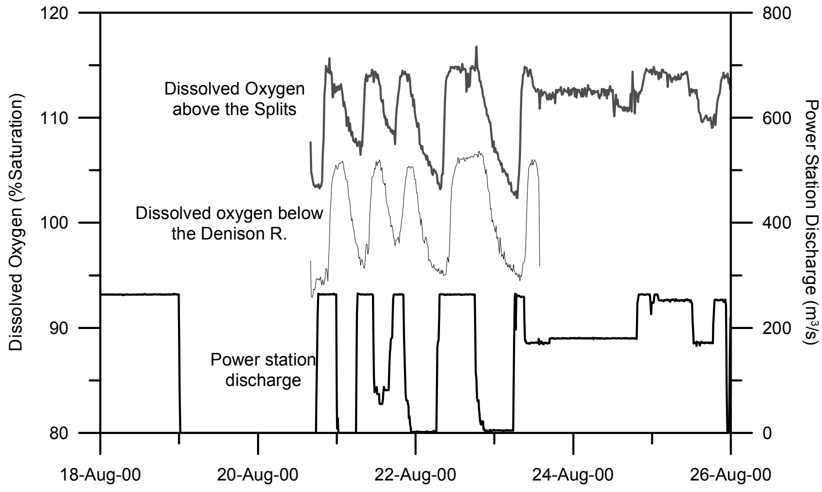


Figure 12. Dissolved oxygen results from the Gordon River above the Splits shown as Percent Saturation of oxygen.

3.3.4 Temperature

Similar to dissolved oxygen, the temperature of water released from the Gordon Power Station is controlled by the conditions in Lake Gordon near the intake. Downstream, the temperature is modified by ambient conditions and the inflow of tributaries. This results in a yearly temperature regime quite different from a 'natural' river, as seen by comparing Figures 13 and 14. Figure 13 contains temperature data from the Savage River, a West Coast river smaller than the Gordon, but with headwaters of similar elevation, and similar seasonal air temperatures. Figure 14 shows water temperature data from the Gordon River 1.5 km below the tailrace and from the Gordon River below the confluence with the Denison River between December 1999 and September 2000. The temperature scales on the two plots are the same, but the time scales are not.

The seasonal trends in the Savage River include maximum summertime temperatures of up to 20 °C, and minimum winter temperatures of 5 – 6 °C. The 9 months of Gordon River data show much less variability through the year, with temperature fluctuations limited to between 8 °C and 12 °C, except for occasional spikes. Comparing the two plots, temperatures in the Gordon are most similar to 'natural' conditions during the autumn (March – April) and spring (August – Sept) when temperatures are about 10°C. Tributary temperatures in March 2000 were similar to March values in the Savage River.

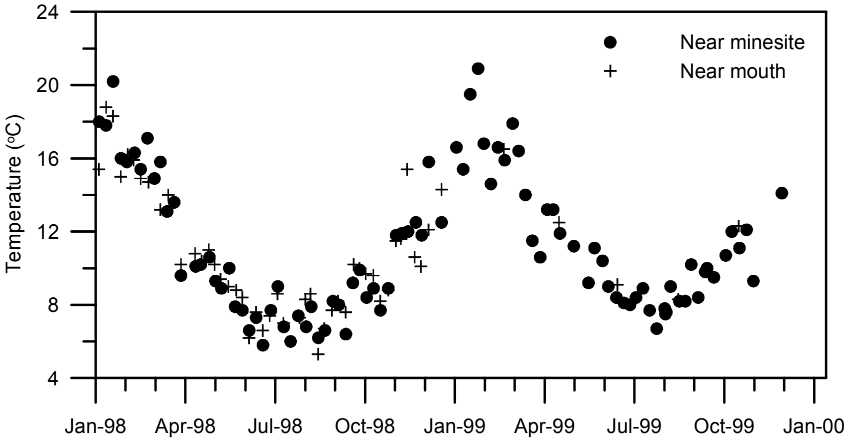


Figure 13. Water temperature at two sites in the Savage River between Jan 98 and Jan 00

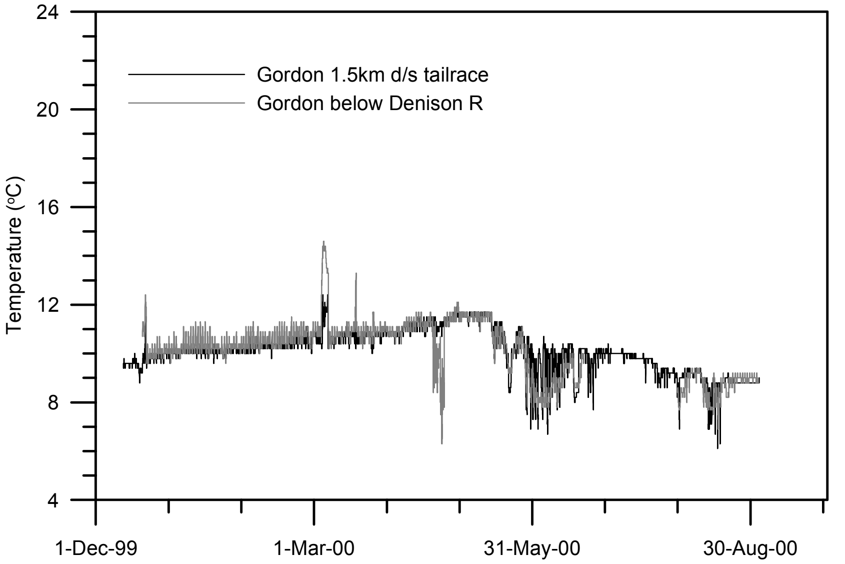


Figure 14. Available water temperature data from the Gordon River 1.5 km downstream of the tailrace, and below the Denison River.

During the March power station on survey (Table 4), temperature increased by approximately 1°C between the tailrace and the Gordon River at Warners Landing, with values approximately 3°C lower than the entering tributaries.

These results are similar to historical temperature surveys completed before and after initiation of operation of the Gordon Power station. Figure 15 shows pre-power station and post-power station temperature regimes in the middle Gordon River. The earlier transects show temperatures increasing downstream of the dam site and then decreasing below the Olga River. The later surveys show lower temperatures, less overall variation and a small increase with distance from the power station. The range of temperature values measured by Christian and Sharp-Paul (1979) in March 1978 after initiation of power station operation is similar to those recorded in the recent survey.

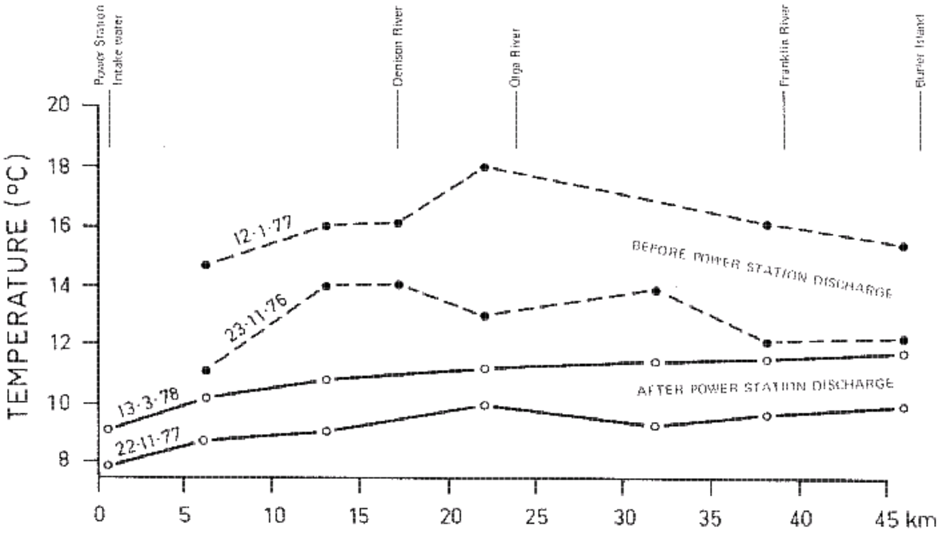


Figure 15. Temperature surveys in the Gordon River below the power station site before and after discharge from the station (Christian and Sharp-Paul, 1979).

Examples of the present effect of various power station operation regimes on the downstream temperature of the river are shown in Figures 16, 17, 18 and 19. Figure 16 shows temperature in the Gordon River 1.5 km below the tailrace and in the Gordon River below the Denison River during a three week period of continuous maximum power station operation (3 turbines operating). Small diurnal temperature fluctuations below the Denison are evident, superimposed on a consistent 10°C temperature regime derived from the power station.

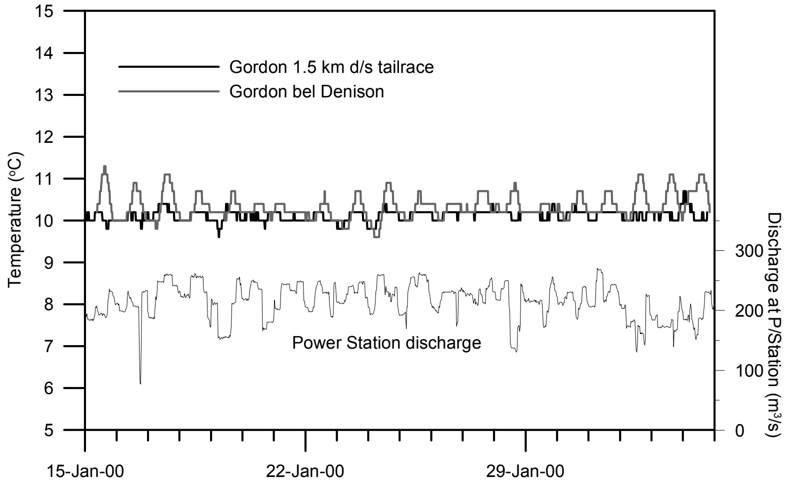


Figure 16. Temperature time-series from two sites in the middle Gordon River during extended maximum power station usage.

Figure 17 shows late summer conditions and a 3-day power station shutdown. Pre- and post- power station shutdown, temperatures are about 10.5°C below the tailrace, with small diurnal increases below the confluence of the Denison River. Following the cessation of power station operation, water temperatures increase significantly, with the Gordon below Denison site warming from about 10.5°C to 14.5°C. This temperature is consistent with 'natural' temperatures for March based on a comparison with the Savage River data.

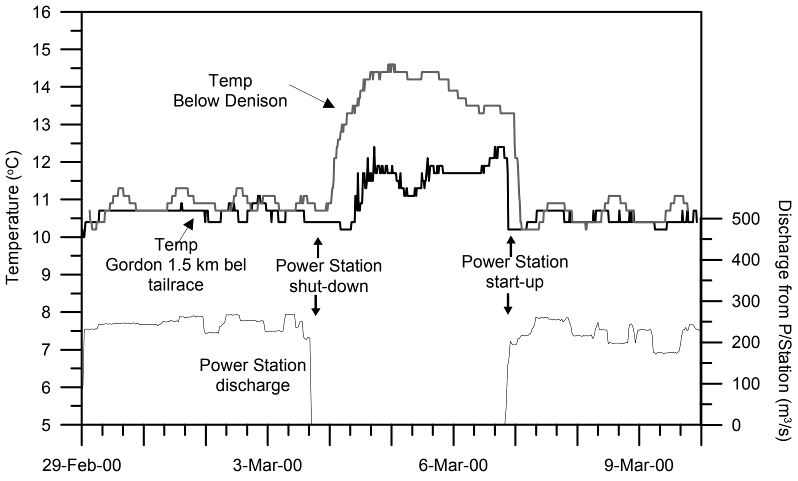


Figure 17. Temperature in the middle Gordon River during a summer shutdown of the Gordon Power Station

The temperature response at the same two monitoring sites to low power station usage during winter is shown in Figure 18. The low power station discharge allows the influx of seasonally cooler water into the Gordon below the Denison, resulting in lower water temperatures (~8°C) as compared to periods of high power station operation (~10°C). The 8°C value is similar to the 'natural' June value in the Savage River. The higher temperatures at the upstream site during periods of power station shutdown are due to pooling and warming of water under the very low flow conditions.

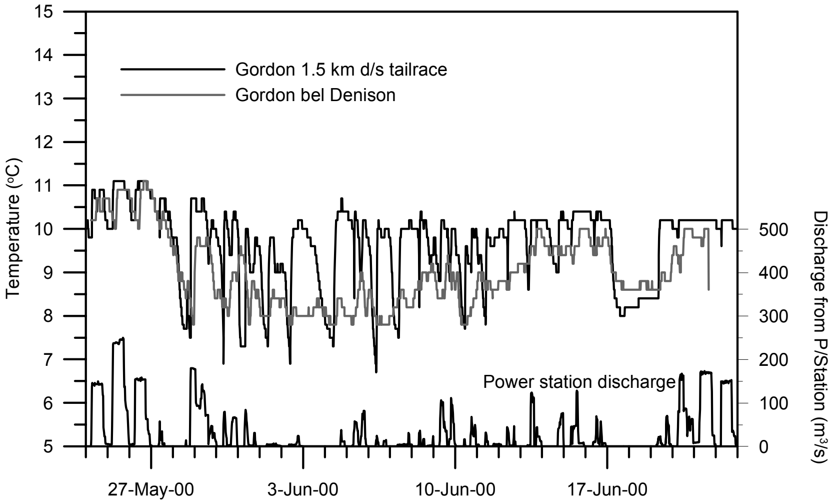


Figure 18. Temperature response in the middle Gordon River to infrequent power station operation

The response of water temperature to rapid fluctuations in power station operation is shown in Figure 19. The graph contains temperature values for the Gordon at the tailrace, Gordon above the Splits, and Gordon below the Denison. Tailrace temperatures during periods of power station shutdown are not reliable. Temperature changes of 0.5°C and 1.5°C are associated with power station operation at the upstream site and downstream Gordon River sites, respectively, with power station off conditions leading to lower more seasonal water temperatures.

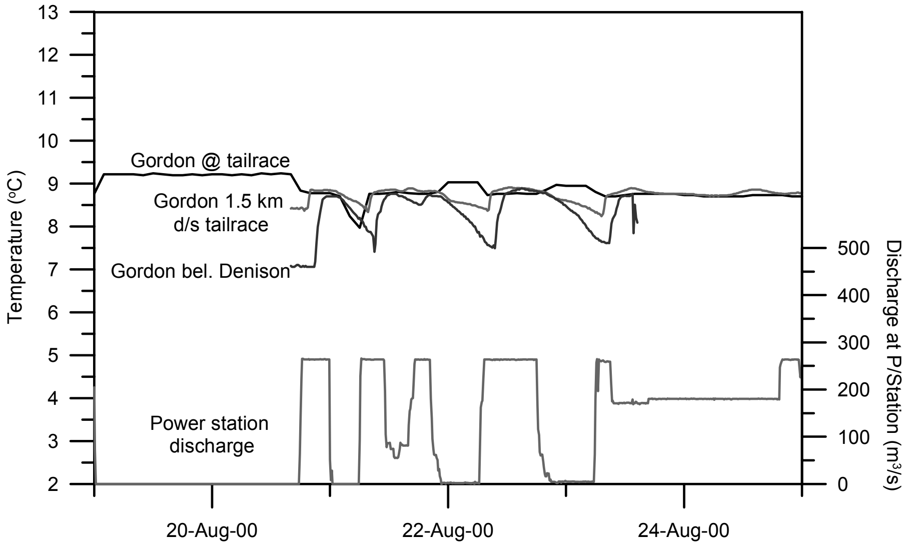


Figure 19. Temperature at the Gordon Power Station tailrace, 1.5 km downstream and below the confluence of the Denison River during frequent power station 'on / off' fluctuations, August 2000

Overall, the present temperature regime of the middle Gordon River is dominated by the discharge of water from the power station which varies between about 8°C and 12°C on an annual basis. ANZECC (1999) guidelines for the protection of aquatic ecosystems recommends that median seasonal temperature should be maintained either below the 80th percentile of the 'reference' condition in the case of increased temperature regimes, or above the 20th percentile of the reference condition in the case of reduced temperatures. Using the Savage River as a reference condition and applying the ANZECC (1999) criteria leads to target summer temperatures in the Gordon River of not less than 15°C, and winter temperatures of not greater than 8.5°C. The use of the much smaller Savage River as a reference condition for the Gordon is not ideal, but it is useful as a general comparison.

Immediately below the power station (Figure 14) winter temperatures are close to this target, at about 9°C during July and August, but summer temperatures are considerably lower at below 12 °C. Figures 17 – 19 show that these seasonal targets are achieved below the Denison River when the power station is either off, or being used infrequently.

3.3.5 Metal concentrations

Table 5 contains metal concentrations for the samples collected during the recent water quality surveys and with the exception of aluminium, all values are well below the ANZECC (1992) water quality guidelines for protection of aquatic ecosystems, with most results also below detection limits.

Aluminium, as previously discussed, is complexed by DOM in the water column and is unlikely to be biologically available. Mercury is discussed in the following section.

Water quality investigations downstream of other hydro impoundments have documented the precipitation of iron-species following the release of iron-rich anoxic water (Ashby *et al*. 1995). This is unlikely to be an issue in the Gordon system, as the depth of the inlet is typically above the zone of complete anoxia, and substantial re-oxygenation occurs within the tailrace prior to discharge to the river system. If anoxic water entered the power station, due to very high lake levels, the precipitation of iron would likely occur in the tailrace. The lack of iron staining in the bedrock river reach below the tailrace tunnel supports that this processes is not common in the Gordon.

Table 4. Water quality information from the Gordon River and tributaries downstream of the power station

			T	EC	DO	DO	pH	Alk.	Ca	K	Mg	Na	Cl	SO_4	DOC
Site	Date	P/S operation	°C	µS/cm	mg/l	% Sat.	lab	mg/l $CaCO_3$	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Gordon tailrace	17/3/00	ON	10.6	35.2	6.11	54	5.5	3	1.40	0.20	0.96	3.85	6.6	1.1	6.0
Gordon d/s Serpentine R	17/3/00	ON	10.5	35.2	6.34	56	5.4 *								
Gordon 1.5 km d/s tailrace	17/3/00	ON	10.6	34.3	10.8	97	5.7	3	1.31	0.21	0.87	3.67	6.5	0.91	5.1
Gordon d/s Albert R	17/3/00	ON	10.7	35.1	10.9	98	5.7	3	1.35	0.17	0.92	3.74	6.5	0.97	6.6
Gordon u/s Splits	17/3/00	ON	10.8	35.2	11.4	100	5.8	3	1.34	0.17	0.91	3.75	6.5	1.0	6.8
Gordon d/s Snake Rapids	17/3/00	ON	10.9	35.0	12.2	110	6.1	3	1.35	0.18	0.93	3.78	6.6	1.0	7.3
Gordon d/s Denison	17/3/00	ON	11.1	36.1	11.9	108	6.4	9	1.68	0.24	1.12	4.04	6.9	1.1	6.6
Gordon d/s Olga	17/3/00	ON	11.3	38.2	11.9	108	6.1	5	1.65	0.17	1.10	3.77	6.7	1.1	7.6
Gordon u/s Franklin	17/3/00	ON	11.2	38.6	11.4	104	6.6	5	1.84	0.22	1.17	4.10	6.7	0.94	7.5
Gordon at Warners Landing	17/3/00	ON	11.2	44.2	10.3	93	6.2	8	2.43	0.21	1.40	3.96	6.9	1.1	5.9
Gordon 1.5 km d/s tailrace	6/3/00	OFF	11.2		10.7										
Gordon d/s Albert	6/3/00	OFF					6.9	20	5.44	0.24	3.35	5.50	8.7	1.3	15.2
Gordon d/s Denison	6/3/00	OFF	14.5		10.1		7.5	52	12.0	0.31	6.84	5.59	8.7	1.2	18.4
Gordon d/s Olga	6/3/00	OFF					7.4	44	11.7	0.32	5.65	6.0	9.5	1.3	19.2
Denison R	17/3/00	Tributary	14.3	151	9.56	93	7.3	62	14.1	0.31	8.46	5.37	8.7	1.3	4.8
Olga R	17/3/00	Tributary	14.0	141	9.82	95	6.9	42	16.0	0.42	2.57	9.41	16	1.7	10
Sprent R	17/3/00	Tributary	14.2	65.4	9.20	89	6.2	2	1.78	0.25	1.22	7.08	12	1.4	15
Franklin R	17/3/00	Tributary	14.6	133	9.24	90	6.9	55	13.3	0.27	5.86	5.20	8.9	1.7	4.0

Table 5. Metal concentrations in the Gordon River below the power station and entering tributaries

			Al	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
Site	Date	P/S operation	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Gordon tailrace	17/3/00	ON	130	<5	<1	<1	<1	3	730	<0.05	13	<1	<5	6
Gordon 1.5 km d/s tailrace	17/3/00	ON	91	<5	<1	<1	<1	<1	619	<0.05	12	<1	<5	3
Gordon d/s Albert R	17/3/00	ON	136	<5	<1	<1	<1	<1	750	<0.05	15	3	<5	5
Gordon u/s Splits	17/3/00	ON		<5	<1	<1	<1	<1	732	<0.05	13	1	<5	8
Gordon d/s Snake Rapids	17/3/00	ON		<5	<1	<1	<1	<1	675	<0.05	12	2	<5	8
Gordon d/s Denison	17/3/00	ON		<5	<1	<1	<1	1	660	<0.05	12	2	<5	5
Gordon d/s Olga	17/3/00	ON		<5	<1	<1	<1	1	642	<0.05	11	2	<5	2
Gordon u/s Franklin	17/3/00	ON		<5	<1	<1	<1	<1	675	0.05	13	3	<5	2
Gordon at Warners Landing	17/3/00	ON		<5	<1	<1	<1	1	742	0.08	14	2	7	11
Gordon d/s Albert	6/3/00	OFF	183	<5	<1	<1	<1	<1	603	0.07	17	<1	<5	<1
Gordon d/s Denison	6/3/00	OFF	141	<5	<1	<1	<1	<1	457	<0.05	10	<1	<5	<1
Gordon d/s Olga	6/3/00	OFF	130	<5	<1	<1	<1	<1	483	<0.05	12	2	<5	<1
Denison R	17/3/00	Tributary		<5	<1	<1	<1	<1	333	<0.05	5	<0.1	<5	7
Olga R	17/3/00	Tributary		<5	<1	<1	<1	<1	849	<0.05	14	3	5	2
Sprent R	17/3/00	Tributary		<5	<1	<1	<1	<1	451	<0.05	13	<1	<5	<1
Franklin R	17/3/00	Tributary		<5	<1	<1	<1	2	388	0.07	13	2	<5	4
ANZECC (1992) Protection of Aquatic Ecosystem			5 if pH<6.5 100 if pH>6.5	50	0.2 - 2		10	2 - 5	1,000	0.1		15-150	1 - 5	5 - 50

3.3.6 Mercury in the Gordon catchment

In the early and mid 1990s, mercury concentrations in trout in Lake Gordon, the Gordon River and Macquarie Harbour were found by the Inland Fisheries Commission to be elevated, though the sample means for samples from the Gordon River and Lake Gordon were below the NH&MRC (1990) health guidelines for human consumption (the recommended application of the guideline is on sample means). Fish in Lake Pedder did not have elevated concentrations. IFC and DELM investigations into mercury concentrations in the sediments in the region found no elevated levels (Koehnken, 1996). A Hydro Tasmania and IFC sponsored PhD study (Bowles, 1998) has provided more information about the distribution of total, dissolved and methylmercury concentrations in Lake Gordon, Lake Pedder, their tributaries, and the lower Gordon River. The following discussion is summarised from this thesis.

Bowles (1998) found that total mercury concentrations were fairly uniform within the lakes, and did not vary with depth, indicating the mercury is not released from sediments. Dissolved mercury was generally found to correlate with total mercury, and contributes about 70% to 90% of the total. Both parameters were correlated with DOC, suggesting that the organic complexation of mercury is an important process. Bowles (1998) also observed that more total mercury enters Lake Gordon than can be accounted for in the discharge from the lake, and attributed the difference to volatilisation of total mercury to the atmosphere.

In contrast to total and dissolved mercury concentrations, methylmercury, the form of mercury that is of biological importance, was found to vary significantly between the lakes, and spatial variations were evident in Lake Gordon. It was concluded that the tributaries contribute significant amounts of methylmercury to both lakes, with rainfall contributing very little. In Lake Pedder, incident rainfall dilutes these concentrations, while in Lake Gordon, dilution is considerably less, and water from the tributaries is mixed with the input from Lake Pedder, to produce intermediate methylmercury concentrations. Additionally in Lake Gordon, the *in situ* methylation of mercury in surface waters was suggested as a potentially important process, and linked to the longer residence time of water in Gordon.

Bowles (1998) estimates that 990 g/year of methylmercury is exiting Lake Gordon each year, which is 470 g/year greater than can be accounted for through inputs, and was suggested as indicating that in-lake methylation of inorganic mercury is important.

Based on a comparison of tributary methylmercury concentrations, and methylmercury concentrations in the Gordon River below the power station, Bowles (1998) suggests that the formation of the lakes has had little impact on the mean annual concentrations of methylmercury released to the downstream environment. This is attributed to the dilution of methylmercury in Lake Pedder offsetting the increase in methylmercury in Lake Gordon due to in-lake processes.

The draft ANZECC (1999) Water quality guidelines for the protection of human consumers of aquatic foods provides a total mercury guideline of 1 µg/L for waterways from which cultured fish, molluscs and crustacea are taken. Total mercury concentrations from Lake Gordon and Pedder as determined by Bowles (1998) were all <0.01 µg/L, with much of the mercury present attributable to particulate sources. The same ANZECC document provides a guideline level of 0.5 mg/kg in edible tissue for the protection of human consumers of fish and other aquatic organisms. The fish sampled by IFC in the early and mid-1990s met this guideline.

3.3.7 Turbidity

Increased levels of turbidity due to the entrainment of sediments and the precipitation of iron and manganese species have been documented in waterways downstream of impoundments (Ashby *et al*,, 1995; Cushman, 1985; Poff, N., 1997). As previously discussed, there is no indication that the precipitation of iron or manganese is a significant processes presently operating in the middle Gordon River (see section 3.3.5).

Visual observations of the middle Gordon River under a range of flow conditions suggest that turbidity is low in the waterway. Suspended sediment measurements were completed under high and low flow conditions at four sites in the river: Gordon River Above and Below the Denison River, and Gordon River Above and Below the Franklin River during August and September 2000. Three depth-integrated suspended sediment samples were collected at each cross-section under each flow condition (Table 6). Under both high and low flow conditions, suspended sediment concentrations were very low, especially at the above and below Denison sites where power station derived flow predominates. Although only two measurements, the results suggest that turbidity in the downstream environment is not high, although no storm events were monitored.

Table 6. Depth integrated suspended sediment concentrations collected during high flow (~200 m^3/s) and low flow (no power station operation) on 22-23/08/2000 (high) and 27/09/2000 (low).

Site	Flow	L.Bank (mg/L)	Centre (mg/L)	R. Bank (mg/L)
Gordon above Denison	High	<1	<1	<1
	Low	2	NA	NA
Gordon below Denison	High	<1	<1	<1
	Low	2	<1	NA
Gordon above Franklin	High	3	3	2
	Low	1	5	3
Gordon below Franklin	High	2	<1	2
	Low	<1	1	6

4 POTENTIAL BASSLINK CHANGES TO WATER QUALITY

Under Basslink, the potential alterations to the Gordon system identified through the TEMSIM modelling include:

- The maintenance of lower lake levels in Lake Gordon as compared to present management practices.
- A change in daily median flow values from the power station, with higher median flows for much of the year with the exception of early summer, and autumn when median flows will be reduced.
- Increased frequency of short-term variability in power station flow discharges (more 'on – off' sequences) and more short duration shutdowns.

Each of these is considered with respect to water quality in the following sections.

4.1 Lower lake levels in Lake Gordon

As discussed in section 2.2.1.1, the water level in Lake Gordon can fluctuate up to 50 m under present management practices. The higher the water level, the greater the depth to the power station intake, which is located a fixed distance from the lake bed, and hence the greater the risk of colder, low dissolved oxygen bearing water being drawn into the power station during the summer months. Although low dissolved oxygen values quickly dissipate in the river system, it is desirable and consistent with Best Practice Environmental Management to reduce the discharge of low dissolved oxygen bearing water as much as practicable. Increasing the temperature of the water released during the summer period would result in downstream temperature values closer to 'natural' seasonal values.

Under Basslink, Lake Gordon will be maintained at levels approximately 10 m lower than under present operating practices (Hydro, 1999). This will have the effect of reducing the water depth to the intake level, and water from relatively higher in the water column will be drawn into the power station (see Figure 3). Water derived from higher in the water column will have higher dissolved oxygen concentrations and warmer temperatures during the summer period, thus reducing the risk of releasing de-oxygenated water. Higher temperature values will reduce temperature differences between power station discharge and downstream tributaries.

Based on the lake profiles collected during the summer of 2000, a relative decrease in the depth of the intake by 10 m would have resulted in a 2°C increase in the temperature of water released by the power station in March 2000, and an increase in dissolved oxygen concentrations of 2 – 6 mg/L (March, June). A temperature increase of 2°C during the summer period would greatly narrow the gap between the 'natural' ambient temperature of between 14 and 20°C, and the current discharge temperature of about 11°C.

Similar to present conditions, any low dissolved oxygen water released under Basslink would be expected to reach acceptable ambient concentrations within 1.5 kilometres of the power station.

This alteration to operations would not be expected to affect the concentrations of mercury or other metals in Lake Gordon or the Gordon River.

4.2 Change to median flow values

On a seasonal basis, the same volume of water will be released from the power station under Basslink during summer and winter as under present operating procedures, but the flow pattern will result in higher median flows for much of the year. This is due to the more bimodal pattern of power station operation under Basslink, with flows either very high or very low in contrast to present patterns that include long intermediate flow periods. Flows in excess of 200 m^3/s are projected to increase under Basslink from 10% to 40% of the time, with flows <30 m^3/s increasing from 15% to 35% of the time. Typical power station flow patterns under Basslink are likely to resemble those shown in Figures 10, 11 and 19 between August 20th and August 23rd, which reflect a Basslink simulation run of the power station.

These changes will affect the relative proportion of power station derived water and tributary derived water in the Gordon River. The range of 'mixtures' will not alter as compared to present conditions, as all flow volumes from the power station as projected under Basslink already occur under the present operating regime, but the distribution of these 'mixtures' with respect to time will change.

The water in the Gordon River will be more similar to power station derived water during high flow 'full-gate' operations, and resemble tributary concentrations during low flow periods, as shown in Figures 10. Although discernible at a chemical monitoring level, this shift would not be expected to have environmental consequences, as all of the water is of low ionic strength and of an excellent quality with only temperature altered by impoundment.

Median flows from the Power Station are expected to be reduced during early summer and autumn, when the station will be used less than under present conditions. Lower discharge during these periods will result in the tributaries contributing a higher percentage of total flow in the river, creating water temperatures closer to 'natural' seasonal values (Figures 17, 18 and 19). This could be beneficial to in-stream biota that rely on seasonal temperature signals as triggers for physiological processes, such as reproduction and migration (M. Howland, pers. com.).

This alteration to operations would not be expected to affect the concentrations of mercury or other metals in Lake Gordon or the Gordon River.

4.3 More frequent, shorter duration operation of the power station

Shorter duration operation of the power station will increase water quality variability downstream of the power station. Similar to changes to median flow volumes, the range of water quality conditions present downstream will not alter, only the frequency and duration. Because both the water discharged from the power station and the water entering the Gordon River below the power station have very high water quality, altering the release pattern of the power station will not alter the compositional water quality in the downstream environment.

Figure 11 shows changes to dissolved oxygen concentration in the river under a Basslink flow scenario. During periods of high flow, dissolved oxygen concentrations are at a maximum due to the turbulent flow in the river. These values decline during periods of power station shutdown. More frequent shorter duration operation of the power station will limit the amount of time the higher dissolved oxygen concentrations are experienced in the lower river system. This would be a positive benefit if total gas saturation is also elevated during power station operation, which it must be stressed has not been determined.

In the event of the release of low dissolved oxygen water from the power station, shorter periods of power station operation would lead to limited exposure of the area immediately below the power station to low dissolved oxygen conditions.

More frequent 'on' / 'off' will also result in more frequent water temperature fluctuations downstream, as the relative contributions of Lake Gordon water and tributary water change. Figure 19 demonstrates that the temperature fluctuations will occur at least as far downstream as the Denison River. As compared to the present operating regime, when power station on conditions can produce uniform temperatures for extended periods of time (Figure 16) Basslink will allow the dominance of tributary derived water in the Gordon at least every few days, and likely on a daily basis. During the early summer or autumn, when the power station is operated less frequently, the influence of the tributaries would be even greater. On a seasonal basis, water temperatures in the river would be expected to fluctuate between about 12°C and 15°C during the summer months, allowing for a only 1 °C increase due to lower lake levels, and between 6°C and 9°C during the winter. Smaller temperature fluctuations will result during the spring and autumn when lake temperatures and tributary temperatures are similar.

This alteration to operations would not be expected to affect the concentrations of mercury or other metals in Lake Gordon or the Gordon River.

4.4 Water Quality Objectives

Six key indicators have been identified for surface waters downstream of Lake Gordon by DPIWE. These include Dissolved Oxygen, Temperature, Total Suspended Solids, Biological Health Rating, Habitat and Faecal coliforms and Enterococci. Biological Health Rating and Habitat are discussed in Appendix 7 of this report series – Gordon River Macroinvertebrate and Aquatic Mammal Assessment (Davies and Cook, 2001). For each of the other key indicators, potential changes under Basslink are discussed below and comments are made as to the availability of relevant data.

The temperature of water leaving the power station is governed by seasonal thermal stratification in Lake Gordon and the relative position of the intake. During the winter, temperature values are close to tributary values, while during the summer, water temperatures are several degrees below tributary values. There is a reasonable amount of data immediately downstream of the power station for this parameter, but very limited information as to how temperature is modified downstream. What is available suggests that during summer, when water temperatures from the power station are depressed relative to tributary values, temperatures increase on the order of 1°C between the tailrace and Warner's Landing (Sir John Falls) during periods of continuous power station operation. During power station shut down, water temperature quickly increases due to tributary inputs.

Basslink will affect temperature regimes in two ways. The maintenance of water level in Lake Gordon at approximately 10 m lower than at present will result in an increase in summer temperatures discharged from the station due to the relatively higher position of the intake in the water column. This will reduce the difference between ambient and Lake Gordon derived water temperatures in the downstream environment. The more frequent on / off operation of the power station will also result in the dominance of tributary derived water in the Gordon River more frequently. This will subject the in stream biota to more seasonal temperatures, albeit on a fluctuating basis, for relatively short durations (hours to several days).

The dissolved oxygen concentration of water leaving the tailrace is controlled by in lake processes in Lake Gordon and the use of air injection in the power station. Data exists for this parameter at the tailrace, however there is no long-term record available downstream.

The Basslink investigations have documented that low dissolved oxygen values rapidly increase downstream of the tailrace due to the natural turbulence of the river. Within short distances, the dissolved oxygen concentrations have been highly modified, indicating that the tailrace data are not applicable to the downstream environment.

During the summer months, downstream power station dissolved oxygen 'on' values were observed to be higher than power station 'off' values, presumably due to the greater turbulence associated with faster water flow during power station operation.

Under Basslink, dissolved oxygen concentrations discharged from the tailrace during summer would be expected to increase even when air injection was not in use due to the relatively higher position of the power station intake in the water column. Downstream, the more frequent fluctuations in power station operation will result in fluctuations in dissolved oxygen values, with higher levels associated with periods of power station operation.

Total Suspended Solids (TSS) has been chosen as an indicator of bank erosion, a topic that is extensively discussed in Appendix 4 of this report series – Gordon River Fluvial Geomorphology Assessment (Koehnken *et al*, 2001). For the middle Gordon River (power station to Franklin River), no time-series of TSS measurements is available. Two sets of measurements completed at high flow (power station on) and low flow (power station off) returned low values (see Table 6). It is suggested that direct measurement of bank erosion, using tools such as erosion pins, scour chains and photo monitoring, as recommended by Koehnken *et al*, (2001) be used to ascertain the degree and rate of bank erosion, rather than a water quality parameter.

Faecal coliforms and Enterococci have been identified as key indicators by DPIWE for secondary and primary contact in the river. There is currently no monitoring of these parameters in the Gordon River, and no historical information is available on Hydro Tasmania's water quality database (Hydrol). Water quality monitoring conducted in other regions of the WHA (Walls of Jerusalem, Lake St Clair, Melaluca) have found very low levels of these indicators in undisturbed areas (Davies and Driessen, 1997). The Gordon River would be expected to have similarly low values, well below the ANZECC water quality guidelines for Primary and Secondary contact. Basslink would not be expected to alter the present range of these parameters in the river.

5 POTENTIAL MANAGEMENT ISSUES

As compared to 'pre-dam' conditions, the construction and operation of the Gordon Power Development has impacted downstream water quality in the following ways:

- Reduced dissolved oxygen concentrations are released from the power station during the summer months, with very low concentrations released during periods of high water level in Lake Gordon
- Potentially elevated total gas saturation levels are created in the Gordon River between the power station and the Olga River due to the highly turbulent flow in the river during extended power station operation
- Potentially elevated total gas saturation levels may be created downstream of the power station due to the use of air injection in the power station
- Reduced and less variable temperature regimes are present in the Gordon River below the power station during the summer months
- The relative proportion of 'upper Gordon catchment' (above the dam site) derived water and lower 'Gordon catchment' (below the dam site) derived water is controlled by discharge patterns at the power station rather than natural flow regimes.

The first four issues, dissolved oxygen concentrations and temperature regimes can affect in stream biota in the downstream environment. Given the high quality of waters throughout the Gordon catchment, it is unlikely that variations in water composition alone have a major impact on the downstream ecosystem. Therefore, only dissolved oxygen and temperature are considered to be potential water quality management issues in the Gordon catchment.

Based on the TEMSIM modelling results, no new water quality management issues are likely to arise under Basslink. The possible discharge of low dissolved oxygen concentrations, the supersaturation of gas in the Gordon below the power station, and the lowering of downstream water temperatures during the summer months remain the primary management issues. Each of these current risks and likely changes under Basslink are summarised below.

5.1 Discharge of low dissolved oxygen water from power station

Dissolved oxygen concentrations are controlled by summer stratification in Lake Gordon, and the relative depth of the intake in the power station. A higher risk of discharging low dissolved oxygen concentrations occurs during the summer, during periods of high lake level and warm ambient temperatures. The recent water quality surveys indicate, however, that the steeply sloping, turbulent nature of the Gordon River immediately downstream of the tailrace results in the rapid re-oxygenation of water. Therefore on a catchment scale, the release of low dissolved oxygen water is not a major management issue.

Under Basslink, this issue is even less significant, as lower lake levels will lead to the intake of water with higher levels of dissolved oxygen.

5.2 Potentially elevated total gas pressures

Supersaturated water with respect to oxygen has been documented in the tailrace during the use of air injection in the power station, and between the Albert River and the Olga River, a reach characterised by a steep slope, numerous rapids and gorges, during periods of high power station discharge.

It is unknown at this time if total gas pressures are also elevated, and the inclusion of this topic as a potential management issue is precautionary only.

The downstream propagation of elevated dissolved oxygen concentrations from the use of air injection is unknown. Because air injection is not used for long periods, but rather as a short term measure as a turbine's output is altered through a specific load, any downstream impact would be expected to occur as a 'spike' of limited duration.

In the Gordon below the power station, the turbulent flow of the river is undoubtedly responsible for the increase in dissolved oxygen concentrations associated with high flow. It is not possible to determine what minimum flow in the Gordon River is required to create the elevated dissolved oxygen concentrations downstream based on the existing data. If it were assumed that a flow rate of 200 m^3/s is required, then under pre-dam and present power station operating scenarios, the total percentage of time these conditions exist would be the same, about 10%. If a flow rate of 100 m^3/s were assumed as necessary, these conditions would have persisted for 25% of the time pre-dam, but are now present about 45% of the time. Under pre-dam conditions, the high dissolved oxygen levels would have corresponded to discrete storm events, separated by periods of base-flow. Under present operating procedures these conditions can persist for weeks at a time.

Under Basslink, because median flows will increase, there is the potential for elevated dissolved oxygen concentrations to occur more frequently than at present. If flows in excess of 200 m^3/s are required to create the high oxygen conditions, then these conditions will be met about 30% of the time, as compared to 10% at present. However, if only a flow of 120 m^3/s is required, there will be no change compared to present power station operating conditions (50% of time).

A major difference under Basslink will be the pattern of elevated dissolved oxygen concentrations as compared to present. As shown in the Basslink simulation in Figure 11, dissolved oxygen values will fluctuate in direct response to power station operation. Because power station operation will be more frequent and shorter in duration, elevated dissolved oxygen levels will not persist for extended periods.

5.3 Less variable temperature regimes

Changes to ambient water temperature can affect the physiology of the biota (growth, reproduction, mobility, migration) and affect ecosystem functioning (ANZECC, 1999). Temperatures in the middle Gordon River are controlled by the water level in Lake Gordon, which affects the relative position of the power station intake, the amount of water released from the power station, the relative influx of water from the downstream tributaries, and ambient air temperature. Present management of the Gordon Power Scheme results in suppressed summer temperatures, and slightly elevated winter temperatures.

Under Basslink, lower lake levels will translate into warmer water being discharged from the power station during the summer. The increase is likely to be on the order of 1 - 2°C at the peak of summer stratification in the lake based on the observations during the summer of 2000. Shorter power station on events year round will allow the dominance of tributary derived water more frequently in the middle Gordon, which will also lead to an increase in summer time temperatures for at least short durations. The reduced use of the power station during early summer and autumn will also result in more seasonable downstream temperatures during these periods.

6 MITIGATION OPTIONS

At present, no mitigation strategies are used to minimise the risk of discharging low dissolved oxygen water or increase the summer water temperatures in the Gordon River below the power station. Possible management options for these issues include controlling lake levels, physical in-lake mixing to degrade seasonal stratification, shifting discharge patterns of the power station to minimise summer releases, and in the case of dissolved oxygen levels, injecting air into the water mass during energy production to increase oxygen levels. Mitigation options for reducing elevated gas levels in the middle Gordon River are not canvassed in this section, as this issue has not been established as being significant. It is addressed in the next section, 'Monitoring'.

Lowering lake levels as a management strategy would result in the intake of more oxygenated and warmer water during the summer months. The implementation of Basslink will result in lowering the range of lake levels maintained in Lake Gordon, effectively implementing this mitigation strategy and increasing dissolved oxygen and temperatures during the summer.

Large scale in-lake mixing to degrade seasonal stratification is a potential mitigation option that would result in uniform temperature and dissolved oxygen profiles during the summer months. This would result in warmer and more oxygenated water entering the power station during this season. In-lake mixing is a very expensive technique that is typically only used in small impoundments. Its application to the deep basin in Lake Gordon would only affect downstream temperatures because dissolved oxygen concentrations are rapidly increased below the power station.

An alternative would be to alter the intake structure such that water closer to the lake's surface could be drawn into the structure during the summer months. This would have the advantage of allowing the selection of water with specific dissolved oxygen and temperature characteristics for intake into the power station regardless of lake level.

Shifting the discharge pattern of the Gordon Power station such that lower or minimal flow occurred during the summer months is another strategy that would reduce the discharge of water containing lower temperatures and reduced concentrations of dissolved oxygen. Because the Gordon is one of only two large, long-term storages in the State this would require analysis and alteration of the entire Hydro generating system.

Dissolved oxygen concentrations could be increased in water exiting the power station through the extended use of air injection during power production or the promotion of turbulence downstream.

Air injection is currently used in the Gordon Power Station on a machine-by-machine basis when the turbines are producing between about 25% and 70% of full load (P. Bottle, pers.com). In order to utilise air injection on a more continual basis, modification of the turbines would be required. Dissolved oxygen concentrations are typically increased by 3 to 6 mg/L (see Figure 5) during the process. This strategy has been used to increase dissolved oxygen concentrations at the John Butters Power Station on the King River and at hydro electric power plants overseas (Wahl, *et al*., 1994). Lake Burbury, the storage for the John Butters Power Station, also stratifies in the summer months, and creating low dissolved oxygen concentrations entering the power station.

Increased turbulence downstream of the power station has been shown to be a naturally occurring process that leads to the rapid re-aeration of water from the power station. Because of this, costly in lake or in power station mitigation options to control dissolved oxygen concentrations are not warranted.

7 MONITORING CONSIDERATIONS

Any further monitoring of Gordon River water quality should consider the following.

Present monitoring of water quality in the Gordon catchment by the Hydro includes the collection of temperature, conductivity, and dissolved oxygen profiles of Lake Gordon six times per year as part of the Hydros routine water quality monitoring program, and continuous monitoring (every 15 minutes) of these same parameters at the tailrace of the power station. Water samples are collected from the lake at various depths and analyses include nutrients and metals.

In situ water temperature probes installed for the Basslink investigations upstream and downstream of the confluence of the Gordon and Denison Rivers should be maintained to allow the collection of detailed water temperature information on a seasonal basis.

As a minimum, this monitoring regime is recommended to be continued before, during and after the transition to ‘Basslink’ conditions in order to detect any unforeseen changes and track long-term catchment trends.

Additional monitoring of total gas pressure in the middle Gordon River during high flow and during the use of air injection is recommended to ascertain whether elevated total gas pressures accompany the elevated dissolved oxygen concentrations. It is important that monitoring sites be located at the tailrace and at as many downstream sites as possible, because of the changes in dissolved oxygen concentrations that are known to occur downstream of the tailrace. If total gas pressures are found to be high, additional monitoring at incrementally lower flows or the installation of a total gas pressure sensor linked to a river level gauge is recommended to ascertain what flow levels lead to the high gas pressures conditions. This is of importance for both the present operating regime of the power station, and Basslink.

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