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Flow requirements for dissolved oxygen in the Waihou River catchment

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Executive Summary

Environment Waikato (EW) is currently in the process of reviewing the status of water resource availability and allocation in the Waihou River catchment. The aim of this project was to evaluate the interactions between dissolved oxygen (DO) and flow in the catchment.

Analysis of long-term DO monitoring data from the Waihou catchment indicates that, in general, DO is not likely to be limiting for aquatic ecology in larger tributaries and the main Waihou River. However, in some of the small lowland tributaries, DO concentrations regularly fell below the recommended protection levels for freshwater fish.

No generalised correlation was identified between daily DO minima and mean daily flow across the range of summer low flows experienced during this study. Other components of the flow regime which were not investigated as part of this study could however interact with DO levels. In the main stem of the river, where DO does not appear to be limiting for ecological communities, if the degree of hydrological alteration is expected to be low, there may be little need to consider DO dynamics in the flow allocation process at the catchment scale unless it affects the assimilative capacity of the river. However, in the smaller tributaries where the aquatic communities are impacted by low DO concentrations it may still be necessary to take DO into account in making flow allocation decisions because of the combined effect of multiple stressors.

It is recommended that, where assimilative capacity can be maintained, water from the main stem of the river can be allocated according to assessments of physical habitat (Jowett 2008) and the natural flow regime (Franklin & Booker 2009). In smaller lowland tributaries where DO is identified as a limiting factor on aquatic communities, precautionary protection levels should be applied to account for the effect of multiple stressors.

1. Introduction

1.1 Background

Environment Waikato (EW) is currently in the process of reviewing the status of water resource availability and allocation in the Waihou River catchment. One of the key objectives of the water allocation process is to ensure the protection of instream values from the effects of water resource use. Jowett (2008) identified minimum flow requirements for fish habitat in the Waihou River and selected tributaries and Franklin & Booker (2009) characterised current flow variability in the Waihou River catchment.

An initial evaluation of dissolved oxygen (DO) dynamics at six lowland stream sites in the Waihou catchment indicated that DO minima under low flow conditions may exceed recommended levels for the protection of instream ecology (Franklin 2010b). Consequently, it was recommended that further monitoring of DO be carried out in the Waihou catchment and that DO depletion be considered in decisions regarding flow allocation.

1.2 Project scope

The aim of this project was to evaluate the interactions between DO and flow in the Waihou River catchment. The purpose of the work was to supplement the initial studies on minimum flow and flow variability requirements for instream ecology, in order to provide a more holistic framework for defining flow requirements in the Waihou catchment.

The main components of the work programme were as follows:

- collation and analysis of historical datasets of dissolved oxygen from within the catchment

- measurement of dissolved oxygen dynamics under low flow conditions at a range of sites in the middle and lower Waihou catchment during summer 2010

- analysis of the interactions between dissolved oxygen and flow using empirical approaches.

2. Methodology

2.1 Long-term data

In order to investigate both long term trends in DO within the catchment and broad scale interactions with flow, historical water quality monitoring and flow data were obtained from EW and the National River Water Quality Network (NRWQN). Water quality data were available from a total of six sites throughout the catchment and were matched to the nearest available flow gauging station record (Table 2.1; Figure 2.1).

Exploratory data analyses were carried out and interactions between flow and dissolved oxygen analysed using linear regression with Pearson correlation coefficients.

Table 2.1: Location of long-term DO monitoring sites in the Waihou catchment.

Site name	Stream name	Location	Easting	Northing	Start date	Sample frequency	Source	Gauging station
W2b	Waihou River	Te Aroha	2749502	6402933	1989	Monthly	NRWQN	Waihou @ Te Aroha
W3	Waihou River	Okauia	2760200	6375600	1993	Monthly	EW	Waihou @ Okauia
W4	Waihou River	White's Road	2757215	6349881	1983	Monthly	EW	Waihou @ Okauia
OR1	Oraka Stream	Lake Road	2753736	6360773	1983	Monthly	EW	Oraka @ Pinedale
WM1	Waiomou Stream	Matamata-Tauranga Road	2762300	6368300	1983	Monthly	EW	Waihou @ Okauia
OH1	Ohinemuri River	Queen's Head	2757600	6417000	1988	Monthly	EW	Ohinemuri @ Queen's Head

2.2 Low flow DO dynamics

Key to the determination of ecological flow requirements with respect to DO is knowledge of DO dynamics under summer low flow conditions. A two pronged approach was used to elucidate the spatial and temporal behaviour of DO in targeted areas of the catchment.

Table 2.2: Location of intensive DO measurements in 2010.

Site	Stream name	Location	Easting	Northing
M1	Mangawhero	SH27 – Waugh farm	2753838	6365852
M2	Mangawhero	SH27 – Voules farm	2754852	6367868
M3	Mangawhero	Totara Springs	2759135	6374030
W1	Waihou	Gordon	2758408	6386022
W2a	Waihou	Te Aroha	2749502	6402933

D-Opto loggers supplied and calibrated by Environment Waikato were deployed to collect temperature (°C) and DO (% saturation and mg L^{-1}) records at five sites in the catchment (Table 2.2; Figure 2.1). This was to identify the short-term temporal variations in DO under summer low flow conditions. The Mangawhero Stream had previously been identified as being susceptible to low DO (Franklin 2010b) and thus this tributary was targeted for monitoring, in addition to the main stem of the Waihou River at Gordon and Te Aroha. The loggers were deployed to the Mangawhero Stream sites on 23 February 2010 and to the Waihou sites at Gordon and Te Aroha on 02 March 2010. All loggers were retrieved and their data downloaded on 16 April 2010. The loggers use a solid-state optical sensing system to measure dissolved oxygen and are considered highly stable over long periods of time. Spot samples of DO and temperature were however taken at the time of logger deployment and retrieval using a YSI Professional Plus handheld multi-parameter instrument to identify any instrument drift that may have occurred.

Following data checking, summary statistics were derived describing the DO dynamics at each site. A time series was plotted and diel variation graphed using boxplots of data at 15 min intervals for each site. Each box encloses 50% of the data, with the median value displayed as a line. The whiskers show values falling within 1.5 times the inter-quartile range, with outliers displayed as individual points. Percentage exceedence curves were also derived for DO concentration at each site. These indicate the percentage of the monitoring period for which a particular DO concentration was equalled or exceeded. Flow dependent relationships with DO were analysed using linear regression and Pearson correlation coefficients. Results were compared to recommended DO levels for protection of freshwater fish in New Zealand (Franklin 2010a) (Table 2.3).

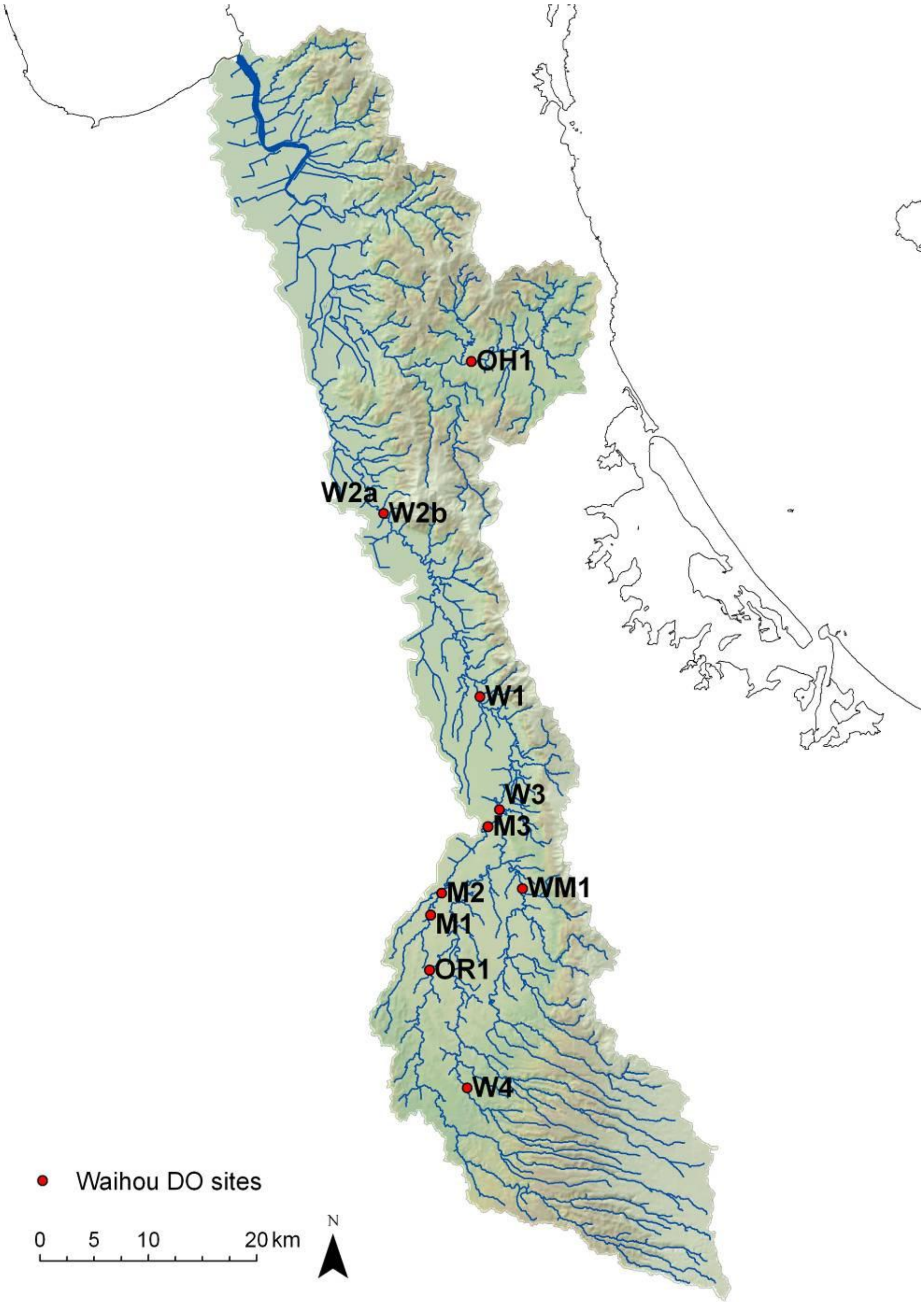

Figure 2.1: Location of DO monitoring sites used for this study. Explanation of site codes is given in Tables 2.1 and 2.2.

In order to identify any spatial bottlenecks in DO conditions in the main stem of the Waihou River and to clarify the representativeness of the chosen monitoring sites, a longitudinal survey of DO was also carried out from Gordon to downstream of Te Aroha. Measurements were made by boat approximately every kilometre along the river, mid-channel, using a calibrated YSI Professional Plus handheld multi-parameter instrument.

In the absence of a flow gauging site in the Mangawhero Stream, two stage recorders were installed in the stream to record variations in water level. The first was located by the SH27 road bridge and the second at the Totara Springs site. Macrophyte growth caused problems with accurate calibration of a stage-discharge relationship.

Table 2.3: Recommended dissolved oxygen levels for protection of freshwater fish. Imperative protection level is the minimum recommended protection level. Guideline protection level should be target protection level or minimum where salmonid species are dominant (Franklin 2010a).

		Early life stages	**Adults**
30-day mean (mg L^{-1})	Guideline	9.0	8.0
	Imperative	6.5	6.0
7-day mean (mg L^{-1})	Guideline	7.5	6.5
	Imperative	5.5	5.0
7-day mean daily minimum (mg L^{-1})	Guideline	6.0	5.0
	Imperative	5.0	4.0
Daily minimum (mg L^{-1})	Guideline	6.0	4.0
	Imperative	4.0	3.0

3. Results

3.1 Long-term data

Long-term dissolved oxygen monitoring data were available from six sites across the catchment. Data were generally spot samples collected monthly and whilst they do not reflect shorter term daily and diel variability, they provide an indication of any long-term temporal trends at these sites (Figure 3.1). Mean DO over the entire time series ranged from 9.3 mg L^{-1} (Lake Road and Te Aroha) to 10.6 mg L^{-1} (Whites Road) between the six sites. DO minima were ≥7.5 mg L^{-1} at all sites except Lake Road on the Oraka Stream, which reached 1.8 mg L^{-1} in November 1985. It is most likely that such a drop in DO would have been associated with a pollution event in the Oraka Stream. Variability in DO was lowest at the Whites Road site on the upper reaches of the Waihou River and greatest at the Queen's Head monitoring site on the Ohinemuri River. Linear regression of DO against date indicated a statistically significant positive trend in the Oraka Stream at Lake Road ($p<0.001$). This largely reflects the lower frequency of low DO events captured in the record post-1990, relative to the period 1983-1990. A statistically significant negative trend was also identified in the Waihou River at Whites Road ($p<0.001$). No clear reason was identified for this result and thus this may indicate a long-term temporal decline in DO at this site. At present, however, DO does not fall below 9 mg L^{-1} in the monthly record and thus the decline is not likely to be ecologically significant. No other significant trends were identified.

No generalised correlation between monthly spot measurements of DO and the corresponding mean daily flow was identified for the six long-term water quality monitoring sites (Figure 3.2). A slight positive trend between DO and flow was identified at all sites except Te Aroha, but the relationship was only statistically significant at the Lake Road site ($p<0.001$). A statistically significant negative trend was identified at the Te Aroha site ($p<0.001$). At all six sites variance in DO appears to be greater at lower flows, but this may just reflect the reduced number of observations recorded at higher flows.

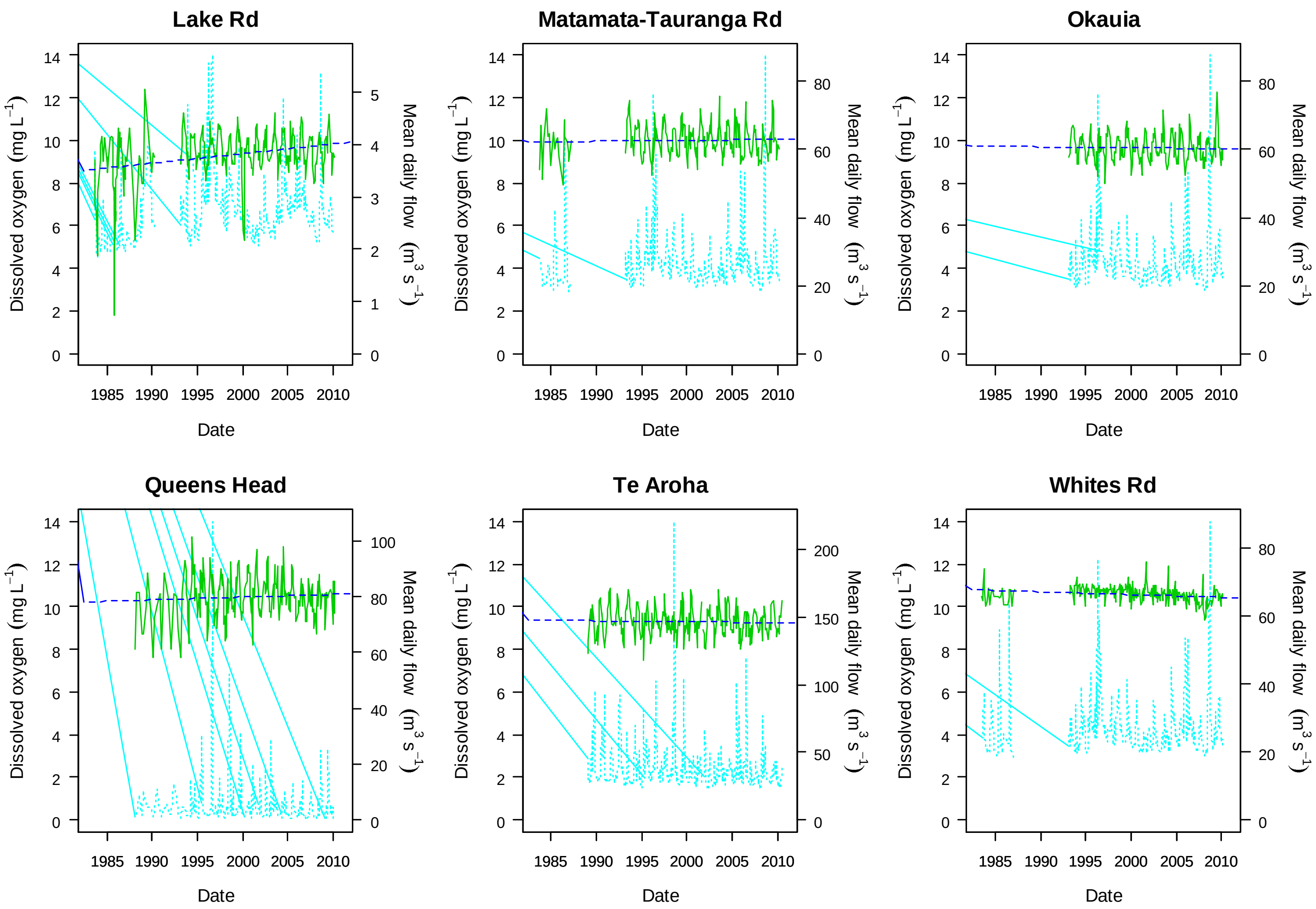

Figure 3.1: Monthly dissolved oxygen time series from six sites across the Waihou River catchment. DO = green solid line, with dashed line indicating temporal trend. Flow = light blue dotted line. For details of site locations see Figure 2.1 and Table 2.1.

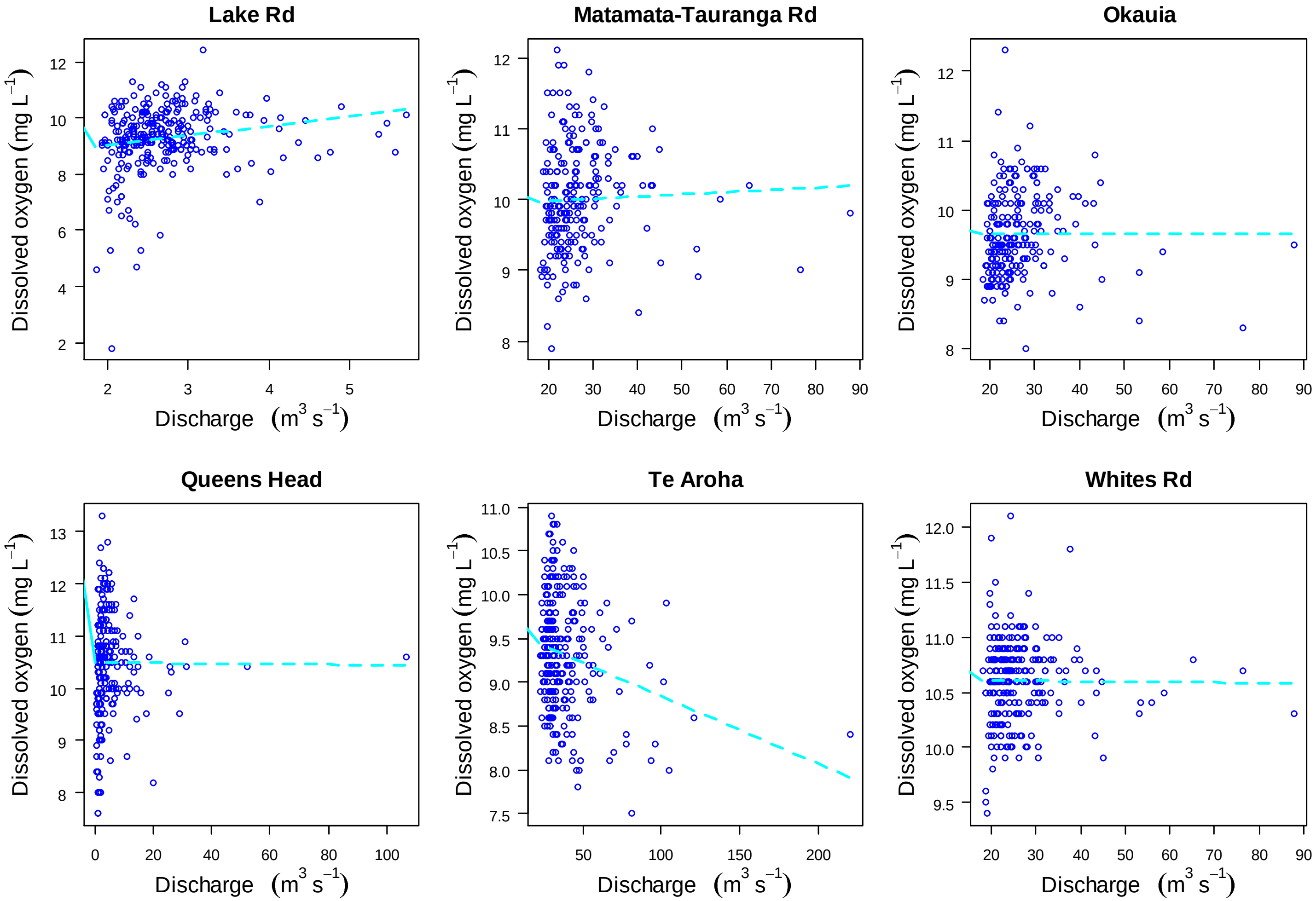

Figure 3.2: Scatter plots of dissolved oxygen against logarithmic$_{10}$ transformation of discharge for the six water quality monitoring sites. Dashed lines are linear regressions indicating interaction between DO and flow. For details of site locations see Figure 2.1 and Table 2.1.

3.2 Low flow dissolved oxygen dynamics

3.2.1 Waihou River

Spatial trends

In order to confirm the spatial representativeness of the two DO monitoring sites in the Waihou River at Gordon and Te Aroha, DO was measured at 1 km intervals along a 50 km reach of the river in a downstream direction (Figure 3.3). The survey was completed over approximately 4 hours, but showed close to constant DO throughout the entire length of the reach (Figure 3.4). Due to the relatively short time between the first and last samples and DO concentrations at Gordon changing by only 0.2 mg L^{-1} over the duration of survey (as recorded by the in-situ D-opto logger), no adjustment to the raw data was deemed necessary to account for the diurnal change in DO that occurs over the duration required to complete the spatial survey. It is noted that there was a difference of approximately 1 mg L^{-1} between the measurements taken using the YSI handheld DO meter and the D-opto logger (with the YSI meter being lower). The YSI meter consistently gave lower readings than all the loggers at deployment and retrieval and thus the difference is likely a consequence of calibration drift in the accuracy of the YSI meter.

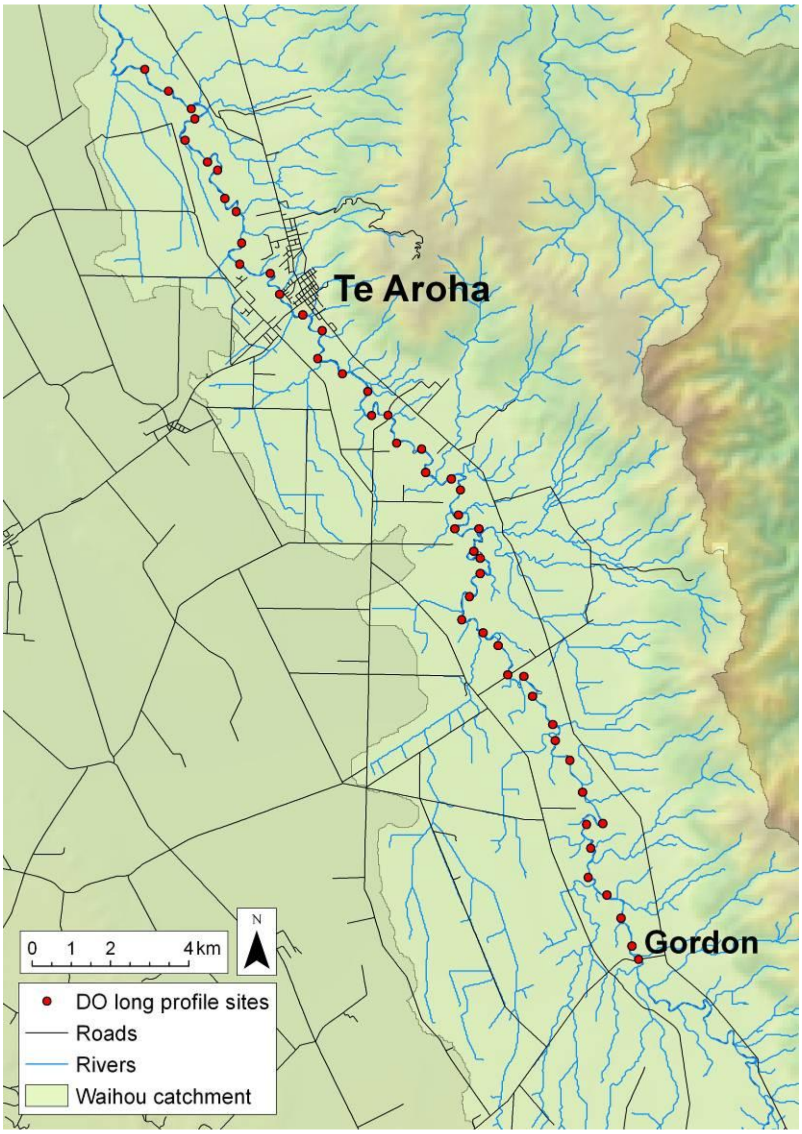

Figure 3.3: Location of sampling points for DO long profile.

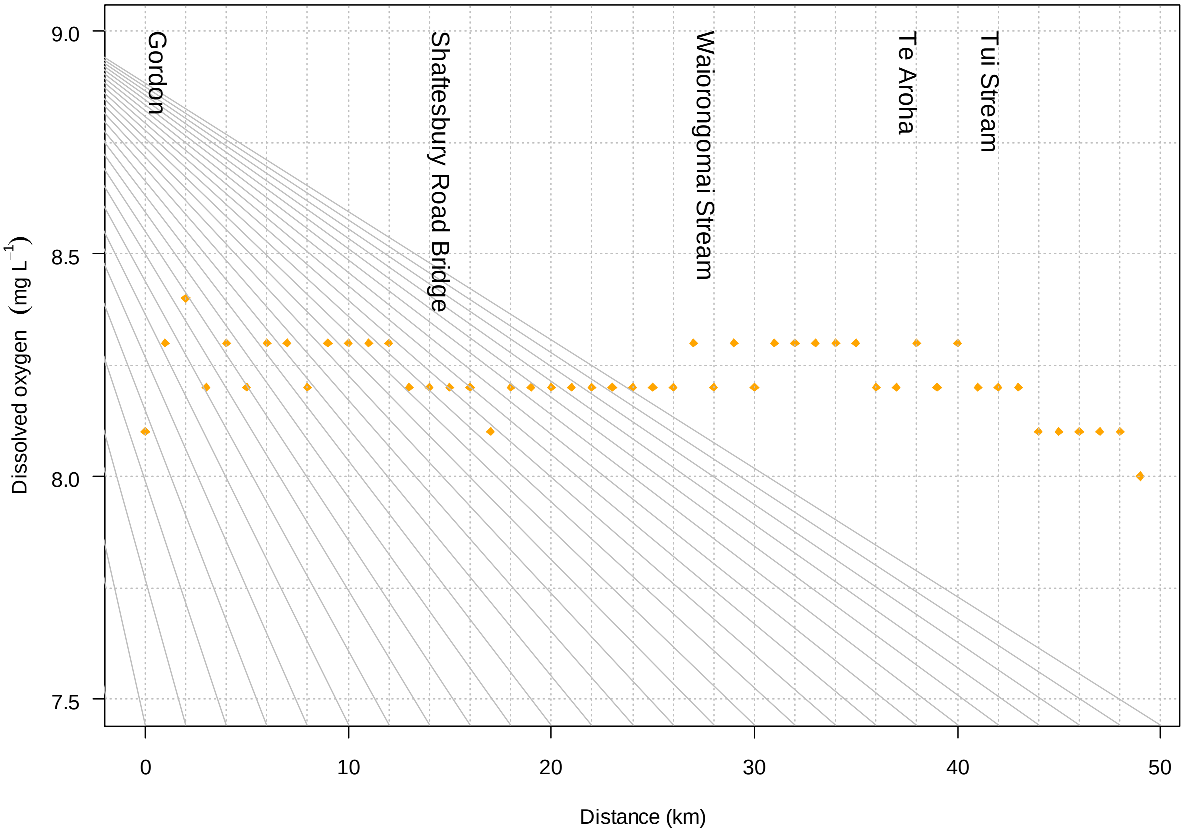

Figure 3.4: Dissolved oxygen long profile in the Waihou River between Gordon (0 km) and downstream of Te Aroha (50 km) for 25/03/2010. Note narrow range of y-axis.

Temporal trends

Water level was recorded at the Gordon DO monitoring site and is closely correlated with the discharge record at Okauia ($p<0.0001$, $r^2=0.94$) (Figure 3.5). Following a small fresh prior to deployment of the DO loggers, flows were relatively low and stable during the monitoring period with the exception of two small freshes on 25 March and 7 April 2010. The flow event at the beginning of February (maximum discharge 52.3 $m^3\ s^{-1}$) was not likely to have been of sufficient magnitude (only c. 2 x median flow) to have any significant flushing effect on the main river and thus will not have confounded the DO monitoring.

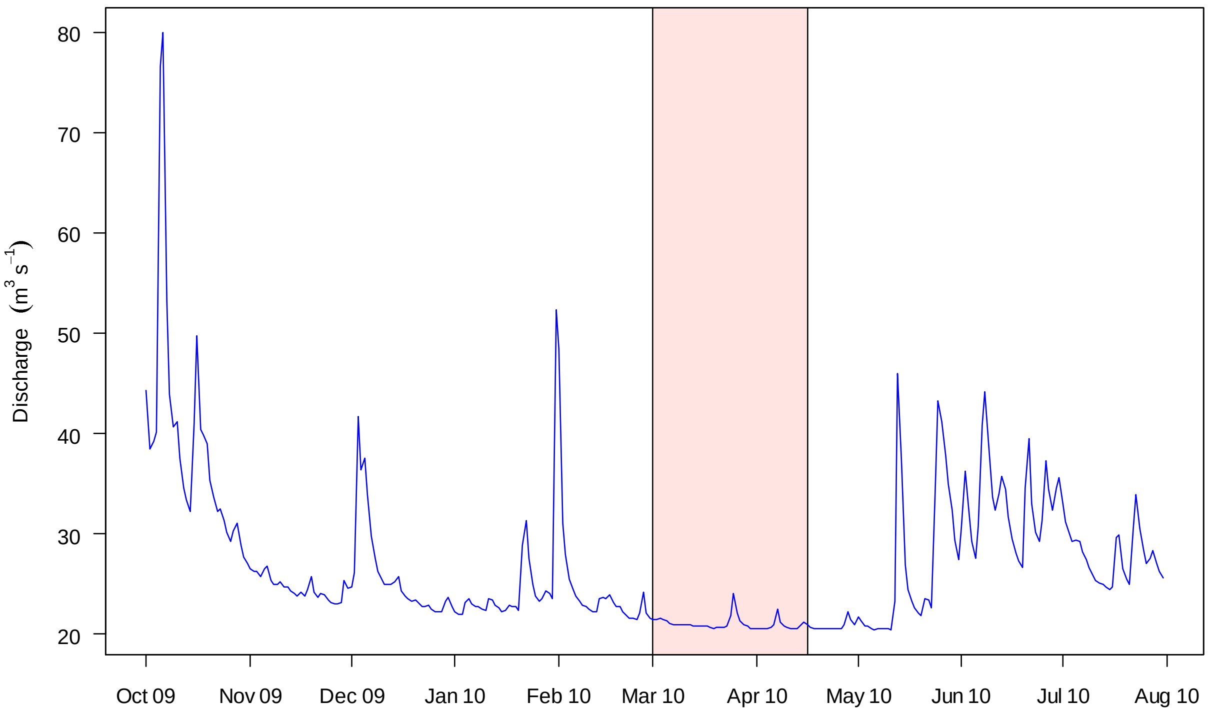

Figure 3.5: Mean daily flow in the Waihou River at Okauia. Red shaded area shows period of DO monitoring.

The DO time series for the Waihou River at Gordon (W1) is shown in Figure 3.6. Unfortunately the logger at Te Aroha (W2a) failed and no data were recorded. Mean DO at W1 over the duration of the monitoring period was 9.6 mg L^{-1}, with a minimum value of 9.0 mg L^{-1} and maximum of 10.5 mg L^{-1} (Table 3.1). A relatively small diurnal cycle in DO concentration was apparent, with a difference between mean daily minimum and maximum DO concentrations of 0.6 mg L^{-1} (Figure 3.7). Both the 7-day and 1-day DO criteria for the protection of fish (Table 2.3) were met throughout the monitoring period (Figure 3.6; Figure 3.8).

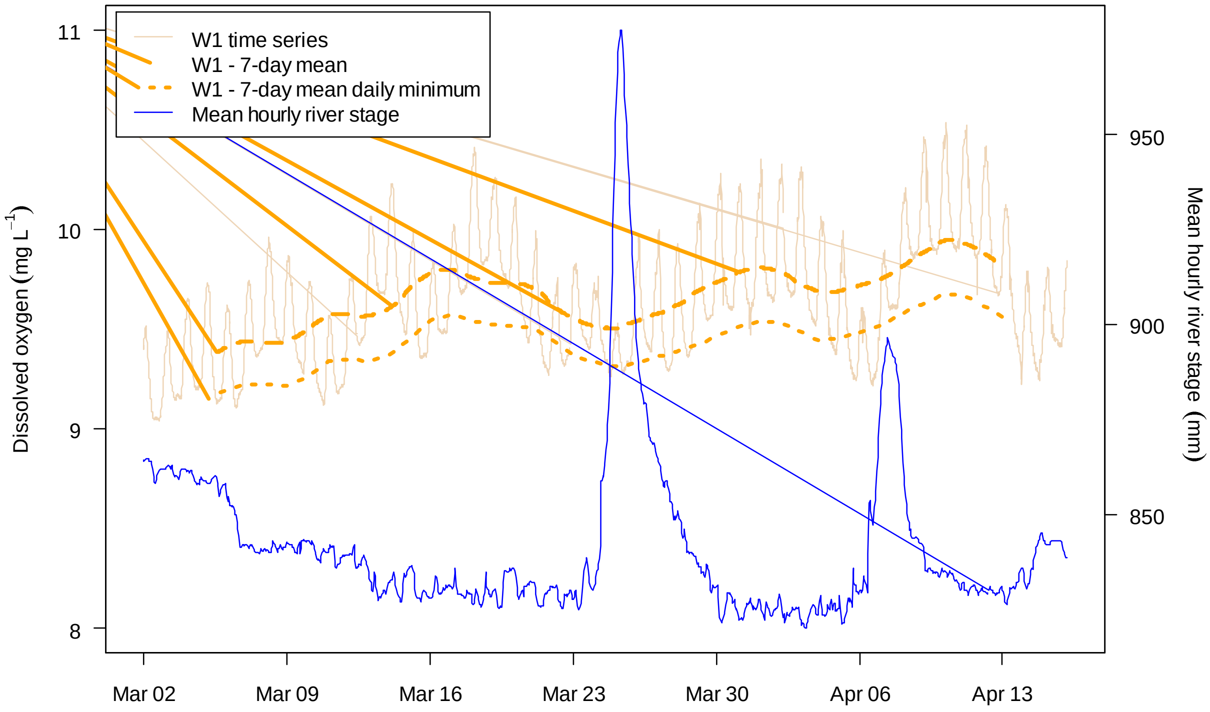

Figure 3.6: Time series of dissolved oxygen concentration, including 7-day means, and river stage at the Gordon monitoring site, Waihou River.

Table 3.1: Summary of dissolved oxygen dynamics at Gordon on the Waihou River.

Parameter	W1
Mean DO	9.6 mg L^{-1} (96%)
Maximum DO	10.5 mg L^{-1} (103%)
Minimum DO	9.0 mg L^{-1} (90%)
Mean daily maximum DO	10.0 mg L^{-1} (100%)
Mean daily minimum DO	9.4 mg L^{-1} (94%)
No. of days minimum DO <3 mg L^{-1}	0
% of time DO <3 mg L^{-1}	0%
Maximum duration of DO <3 mg L^{-1}	0 hours

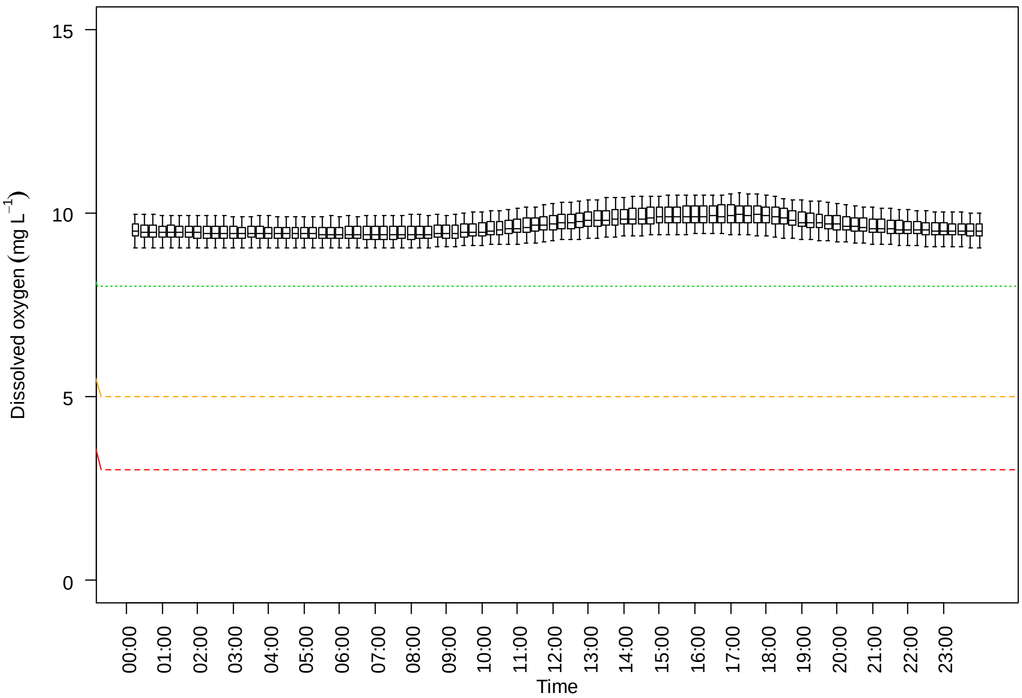

Figure 3.7: Boxplots showing mean diel variability in dissolved oxygen concentration at the Gordon monitoring site on the Waihou River. Dashed lines show recommended DO concentrations for adult fish (Green (8mg L^{-1}) = Guideline 30-day mean; Orange (5 mg L^{-1}) = Imperative 7-day mean; Red (3 mg L^{-1}) = Imperative 1-day minimum).

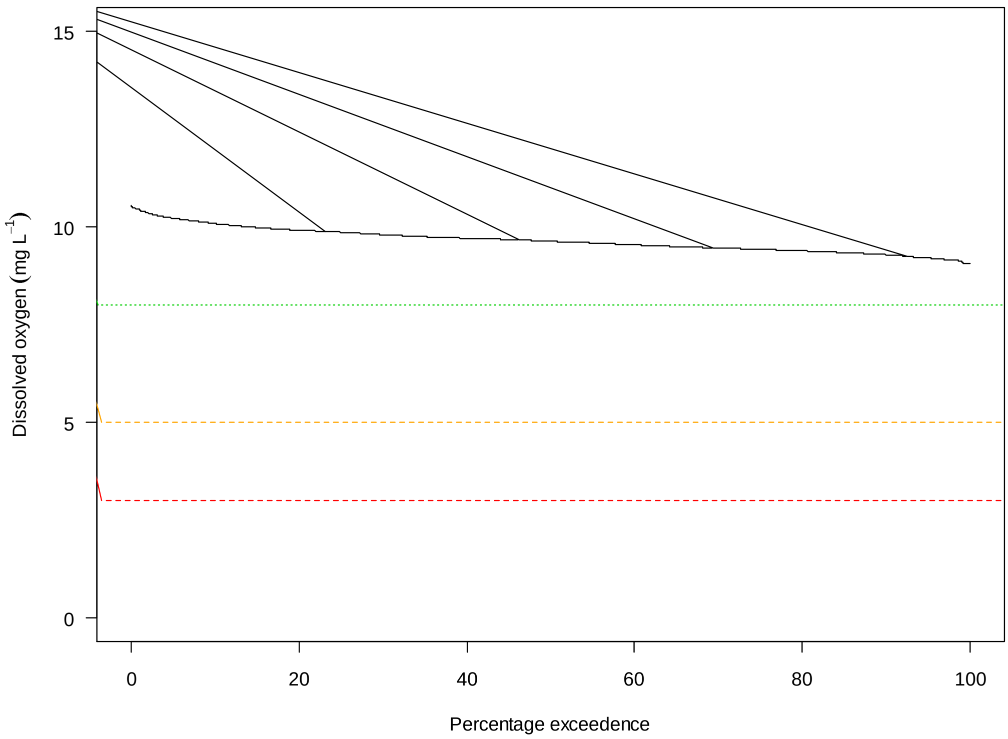

Figure 3.8: Dissolved oxygen duration curve for the Gordon monitoring site on the Waihou River. Dashed lines show recommended DO concentrations for adult fish (Green (8mg L^{-1}) = Guideline 30-day mean; Orange (5 mg L^{-1}) = Imperative 7-day mean; Red (3 mg L^{-1}) = Imperative 1-day minimum).

Over the range of flows experienced during the summer low flow monitoring period, a weak negative correlation was present between daily dissolved oxygen minima and water level ($p=0.007$, $r^2=0.13$) (Figure 3.9). However, due to the very low number of DO observations at higher water levels (>860 mm), significant caution must be taken in interpreting this result. This correlation is reflected in the DO and river level time series (Figure 3.6), which show a depression of DO at the time of the two small freshes during the monitoring period. DO minima appear to occur at a similar time to the peaks in river level, but the decline in mean daily DO occurs in advance of the rising limb of the hydrograph. This raises questions over the main driver for the observed changes in DO and would require more detailed analysis which is beyond the scope of the current work.

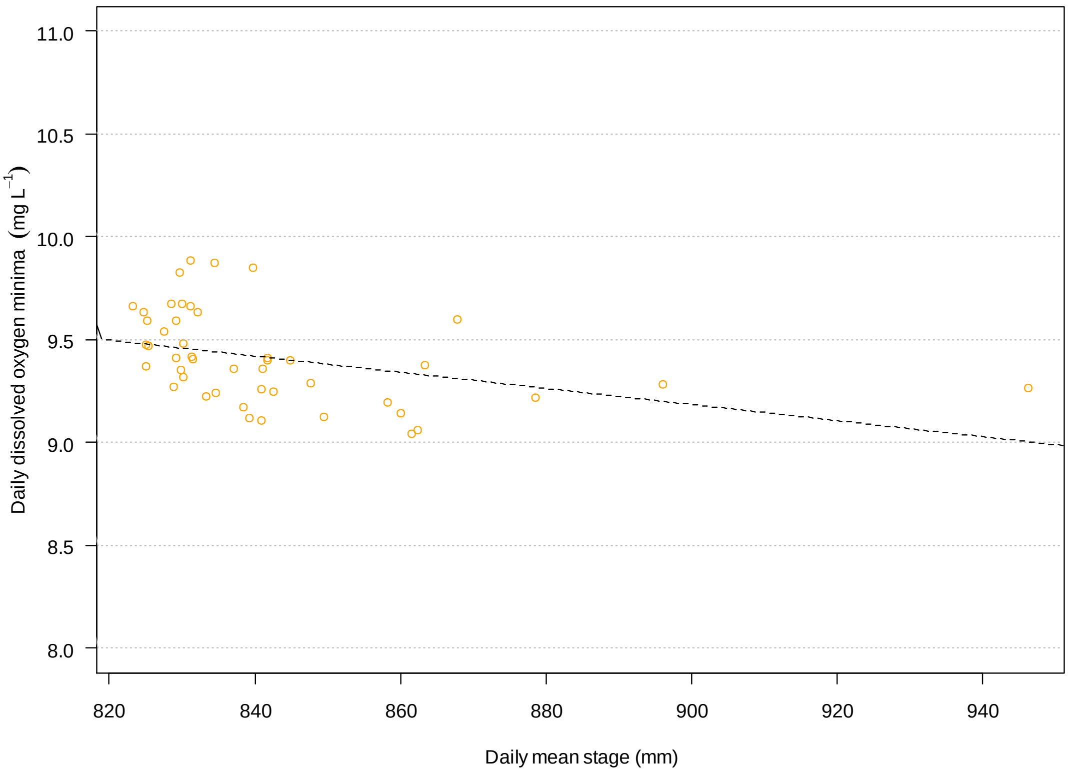

Figure 3.9: Scatter-plot of daily dissolved oxygen minima versus daily mean stage for the Gordon monitoring site, Waihou River. Dashed line shows linear regression ($p=0.007$, $r^2=0.13$).

3.2.2 Mangawhero Stream

Water level was recorded at two locations in the Mangawhero Stream. Due to high macrophyte growth and a relatively low range of flows over the monitoring period, it was not possible to establish a robust stage discharge relationship for either site. Water levels for both sites are therefore presented in Figure 3.10 to give an indication of flow conditions in the river during the monitoring period. Both hourly and mean daily water levels are presented so that small scale variations can be compared to the general daily trend. On 16 April 2010, discharge was measured at 0.01 $m^3 s^{-1}$ and 0.98 $m^3 s^{-1}$ at the SH27 and Totara Springs sites respectively. At both sites, flow was relatively stable between mid-February and mid-April reflecting typical late summer/early autumn low flows. Water levels were slightly elevated on two occasions, once in late February and the second in late March. Water level at Totara Springs (downstream site) responded more rapidly to the rainfall than at the upstream site at the SH27 road bridge. This suggests that surface run-off is a more important flow pathway at the downstream site, but will also reflect the low drainage density in the upper part of the catchment.

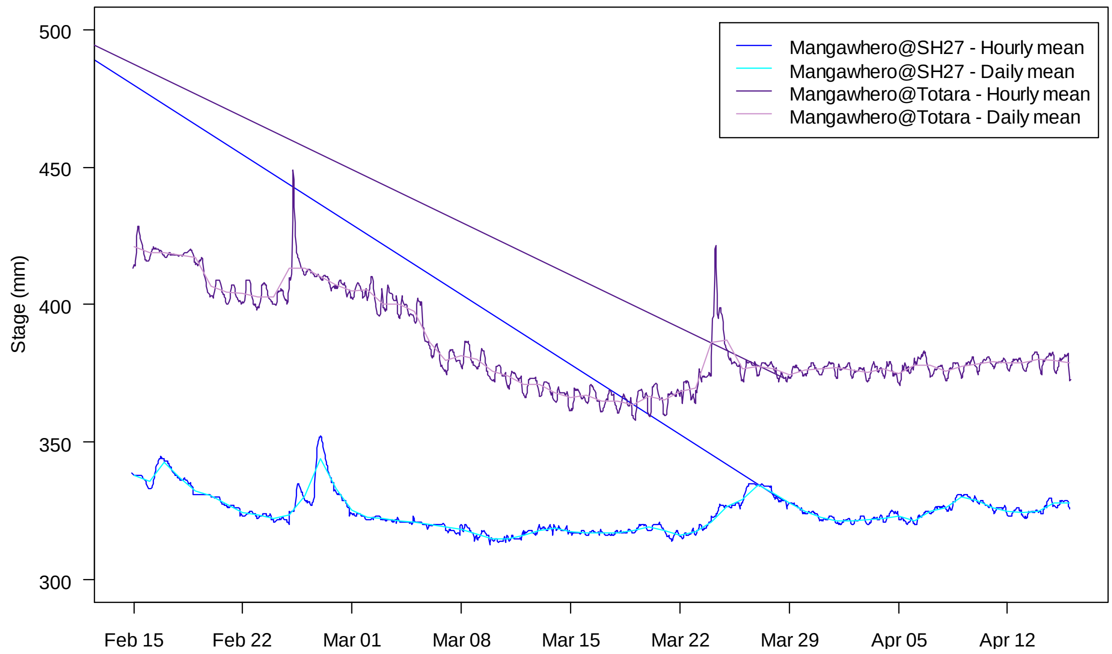

Figure 3.10: Mean hourly and daily water level in the Mangawhero Stream at SH27 and Totara Springs. Stage is relative to local benchmarks and thus not directly comparable between sites.

The dissolved oxygen time series for the three Mangawhero Stream monitoring sites are shown in Figure 3.11. Unfortunately, problems with the DO loggers meant that complete time series were not collected at sites M2 and M3. DO conditions at M1 were significantly different to the other two sites, with a mean DO concentration over the monitoring period of only 0.5 mg L^{-1}, compared to 8.4 mg L^{-1} and 9.2 mg L^{-1} for sites M2 and M3 respectively (Table 3.2). Previous surveys have also indicated very low DO in the vicinity of site M1 (e.g. Franklin 2010b). The cause is unclear and may require further investigation. It is possibly associated with low re-aeration potential due to excessive macrophyte growth, or run-off from adjacent land-use.

All three sites displayed a diurnal cycle in DO concentration, with the greatest range of variability observed at M3 where the difference between mean daily minimum and maximum DO concentration was 2.4 mg L^{-1} (Figure 3.13; Table 3.2). This diurnal pattern is a result of the shift in dominance between photosynthesis by aquatic macrophytes during daylight hours and respiration at night. The relative difference in diurnal range between the three sites can be explained by the relative abundance of submerged aquatic macrophytes at each of the three sites.

Table 3.2: Summary of dissolved oxygen dynamics at the three Mangawhero Stream sites.

Parameter	M1	M2	M3
Mean DO	0.5 mg L^{-1} (4.8%)	8.4 mg L^{-1} (84.7%)	9.2 mg L^{-1} (95.6%)
Maximum DO	15.7 mg L^{-1} (157%)	10.9 mg L^{-1} (114%)	12.5 mg L^{-1} (132%)
Minimum DO	0.0 mg L^{-1} (0.0%)	6.9 mg L^{-1} (69.7%)	6.5 mg L^{-1} (63.4%)
Mean daily maximum DO	2.3 mg L^{-1} (23.0%)	9.1 mg L^{-1} (93.8%)	11.3 mg L^{-1} (119%)
Mean daily minimum DO	0.04 mg L^{-1} (0.4%)	7.9 mg L^{-1} (79.8%)	7.9 mg L^{-1} (81.2%)
No. of days minimum DO <3 mg L^{-1}	51	0	0
% of time DO <3 mg L^{-1}	97.8%	0%	0%
Maximum duration of DO <3 mg L^{-1}	668 hours	0 hours	0 hours

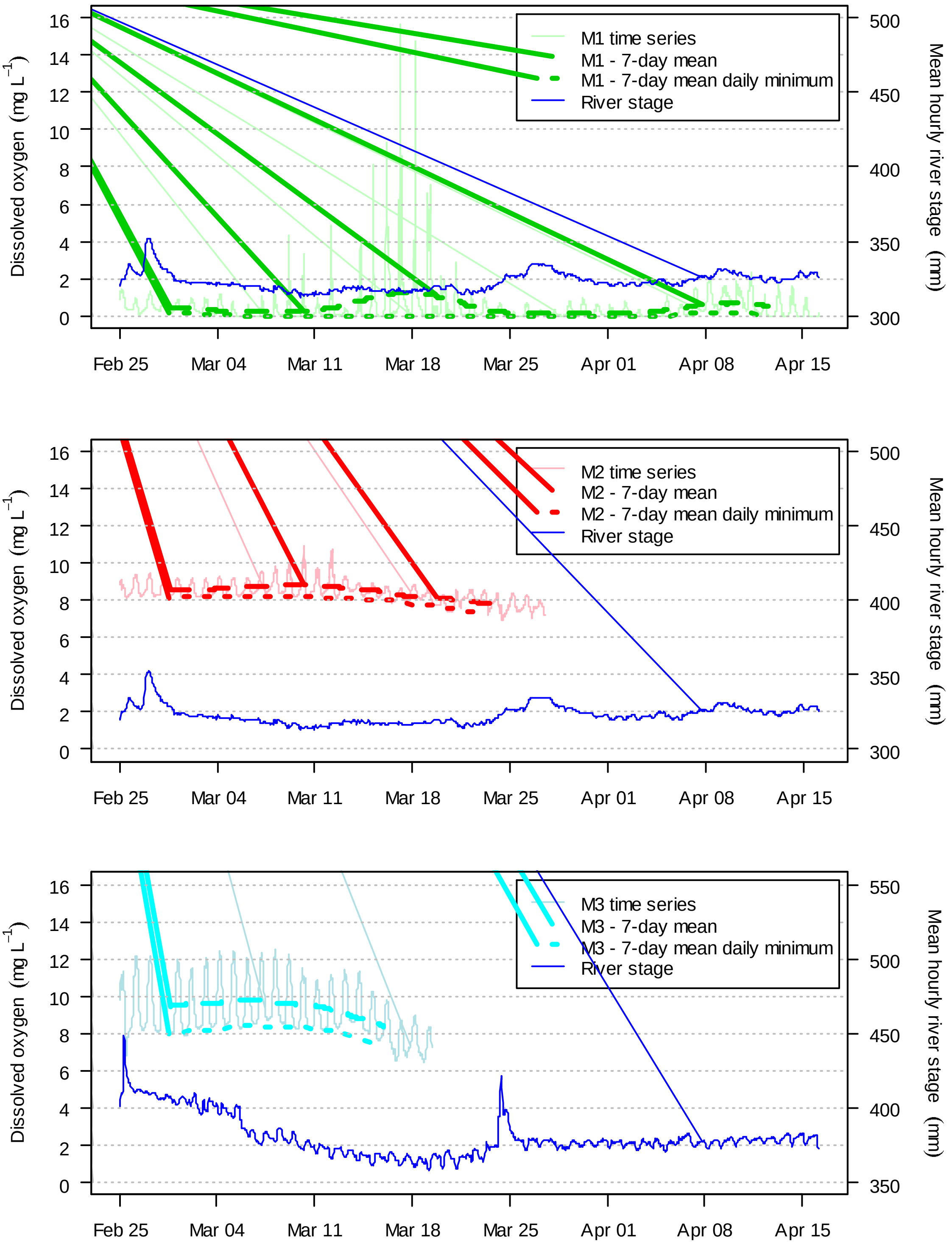

Figure 3.11: Time series of dissolved oxygen concentration and river level at the three Mangawhero Stream monitoring sites. The loggers at sites M2 and M3 became covered in macrophytes during the middle of the study period resulting in inaccurate DO readings which have been removed.

DO minima at both M2 and M3 did not fall below 6.0 mg L^{-1}, the minimum 30-day mean protection level for fish. For the majority of the time, DO at both sites also exceeds the guideline 30-day minimum protection level of 8.0 mg L^{-1} for sensitive species such as salmonids. The 7-day mean DO concentrations also remained above the recommended protection levels at both sites (Figure 3.11). This suggests that fish communities should not be impaired by low DO at these sites. However, at M1 the minimum DO recorded was 0.0 mg L^{-1} and the mean daily minimum was 0.04 mg L^{-1}. This is below the lethal tolerance level of most freshwater fish species in New Zealand (e.g. Dean & Richardson 1999). Figure 3.14 shows DO duration curves for the monitoring period. These give an indication of the percentage of time over the monitoring period for which a particular DO concentration is equalled or exceeded. At M1 DO concentrations were below the recommended 1-day minimum DO of 3 mg L^{-1} for 97.8% of the time and were continuously below this threshold for up to 28 days continuously (Table 3.2). They were also below 1 mg L^{-1} for approximately 90% of the monitoring period and for up to 14 days continuously (Figure 3.14). It is likely that fish communities at this site would be significantly impoverished.

The diurnal range of DO was extremely exaggerated over a week long period in mid March at M1. The reason for this is unclear, but it does coincide with a period of reduced temperatures (Figure 3.12). However, a similar magnitude of response is not observed when temperatures drop further during early April suggesting that temperature may not be the cause. Malfunction of the DO logger cannot be ruled out. The elevated flows around 25 March, appeared to have very little impact on DO dynamics.

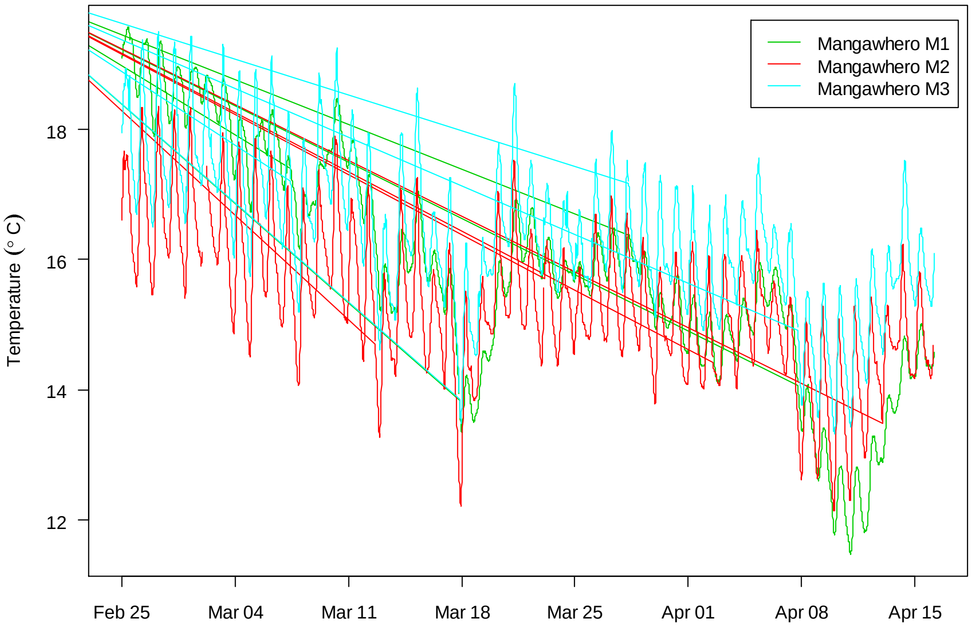

Figure 3.12: Water temperature times series at the three Mangawhero Stream monitoring sites.

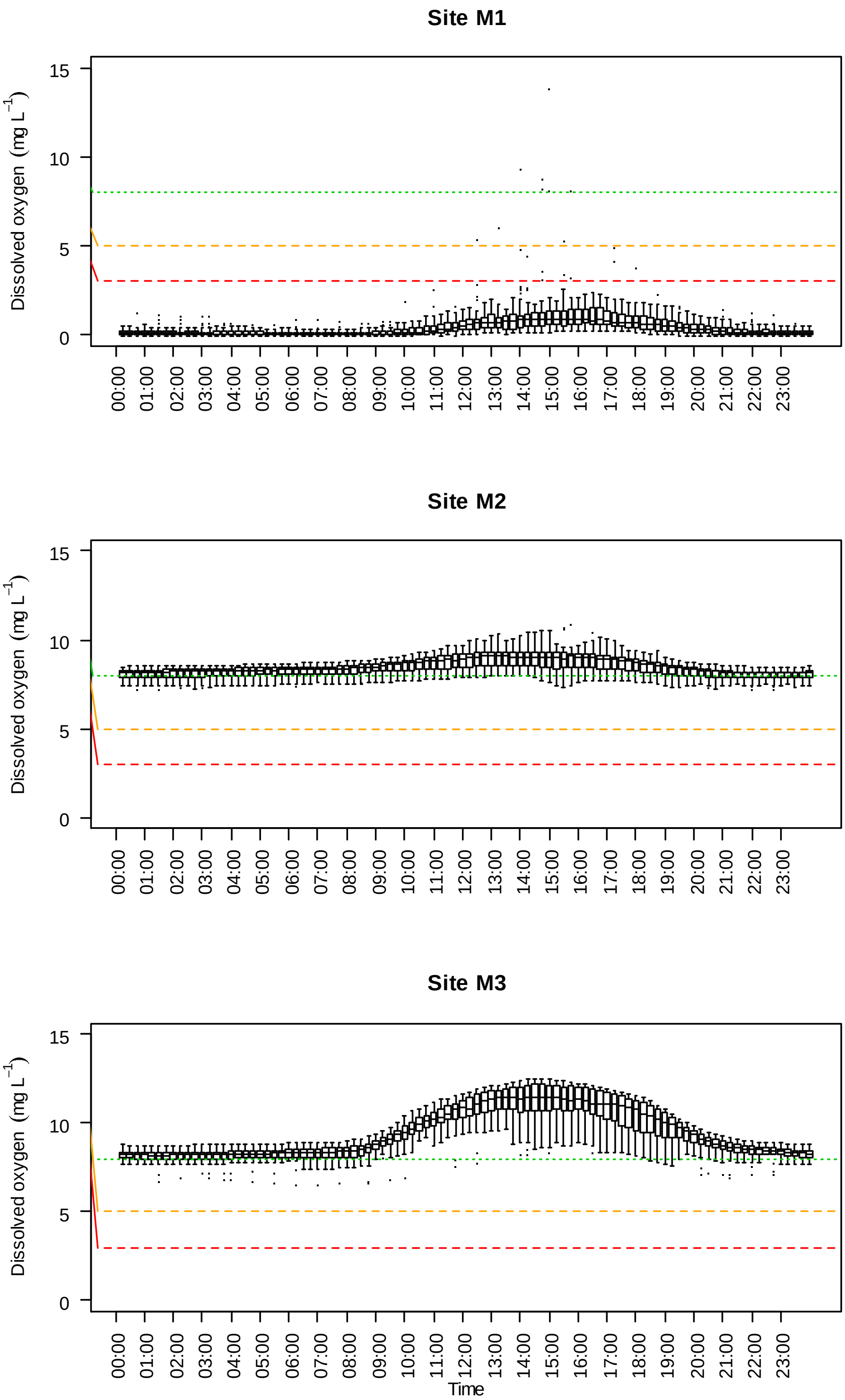

Figure 3.13: Boxplots showing mean diel variability in dissolved oxygen concentration at the three monitoring sites in the Mangawhero Stream. Dashed lines show recommended DO concentrations for adult fish (Green (8mg L^{-1}) = Guideline 30-day mean; Orange (5 mg L^{-1}) = Imperative 7-day mean; Red (3 mg L^{-1}) = Imperative 1-day minimum).

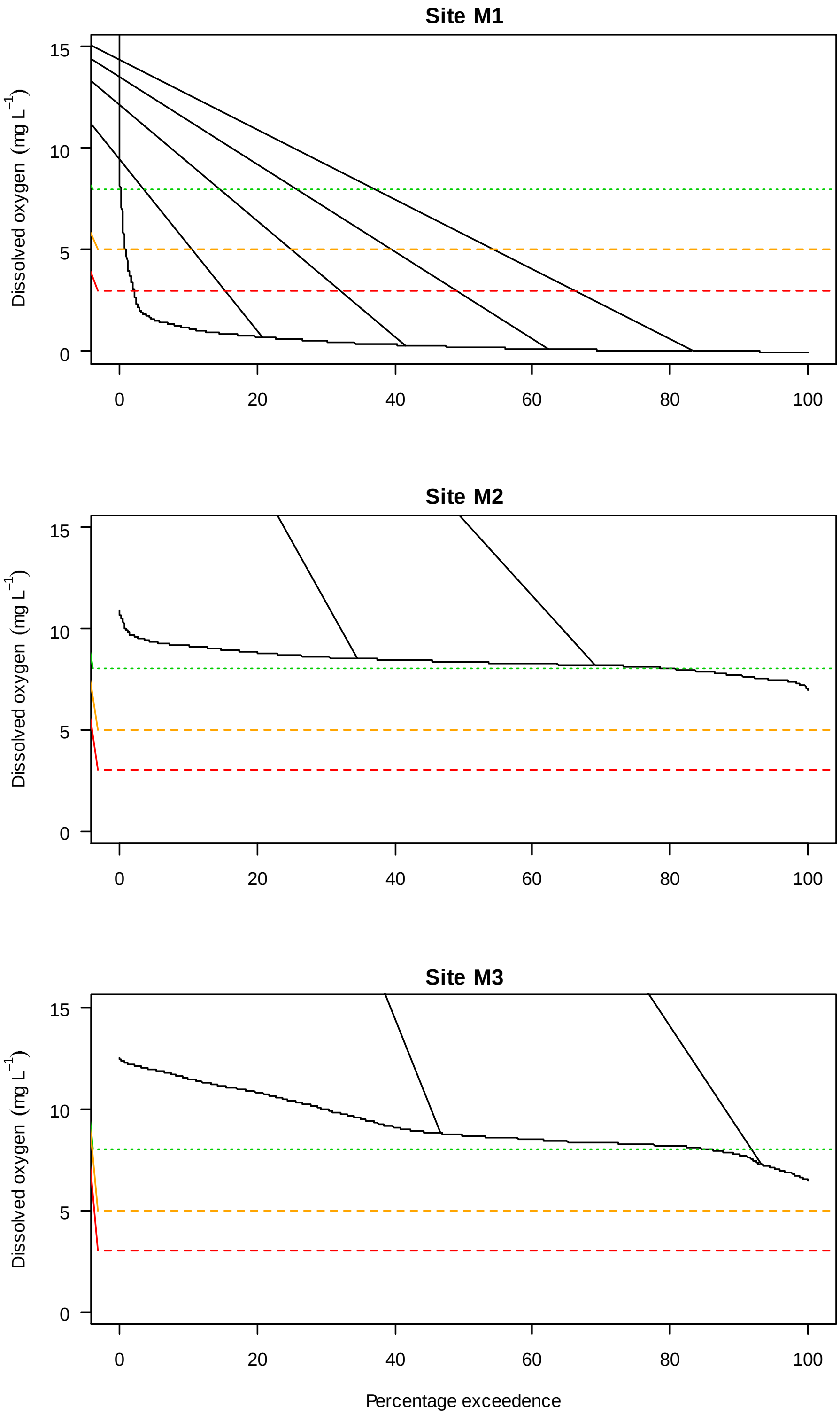

Figure 3.14: Dissolved oxygen duration curves for the three Mangawhero Stream monitoring sites. Dashed lines show recommended DO concentrations for adult fish (Green (8mg L^{-1}) = Guideline 30-day mean; Orange (5 mg L^{-1}) = Imperative 7-day mean; Red (3 mg L^{-1}) = Imperative 1-day minimum).

Exploring the relationship between flows and dissolved oxygen further shows that over the relatively limited range of flows experienced during this survey, there is no clear trend between mean daily river level and daily DO minima (Figure 3.15). Linear regression of daily DO minima against daily mean stage showed no statistically significant relationship at sites M2 and M3 ($p>0.4$). A slightly significant positive relationship between the two variables was found at M1 ($p=0.014$), but r^2 values were less than 0.1 indicating poor explanatory power. Over this narrow range of flows, at these sites, it appears therefore that changes in mean daily flow have relatively limited impact on dissolved oxygen concentrations. It is however noted that mean DO was greater where stream size, and hence flow, was also higher (Sites M2 and M3 relative to Site M1). Further analysis over a greater range of flows and of different flow variables would be necessary to elucidate the interactions between flow and DO.

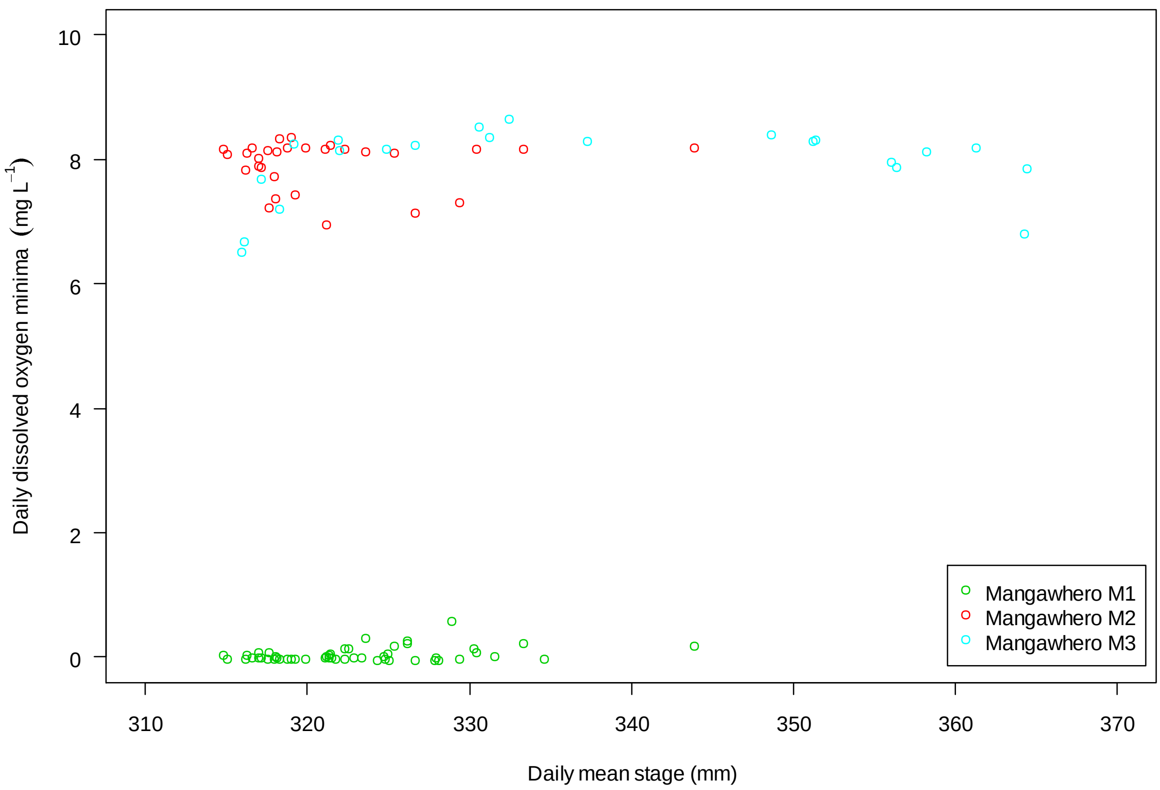

Figure 3.15: Plot of daily dissolved oxygen minima versus daily mean water level for the three Mangawhero Stream monitoring sites. M1 and M2 are plotted against the upstream stage recorder and M3 against the downstream stage recorder.

4. Discussion

Oxygen is essential for the process of respiration and dissolved oxygen can therefore be a limiting factor to many aquatic organisms. Consequently, the DO concentration of water is a key control of habitat quality and a critical measure of stream health. Low DO is most commonly encountered in un-shaded, slow-flowing, lowland rivers where aquatic plants are abundant. Increasing evidence is emerging to indicate that in some lowland streams DO is falling below acute limits for fish (Dean & Richardson 1999, Franklin 2010a, Wilding 2007). Where DO has the potential to act as a limiting factor on ecological communities, it is important that it is considered within the process of ecological flow determination.

Analysis of the long-term DO monitoring data within the Waihou catchment indicates that, in general, DO is not likely to be limiting for aquatic ecology in larger tributaries and the main Waihou River. A statistically significant decline in DO over the last 25 years was however identified in the Waihou River at Whites Road. Due to it being located in the upper part of the catchment and the fact that this site has the highest mean DO concentration of the six long-term monitoring sites, this may be of limited immediate concern for water allocation at the catchment scale, but should be taken into consideration when allocation decisions are being made and the causes investigated.

The higher intensity DO monitoring carried out during the summers of 2009 and 2010 (Franklin 2010b and this study respectively) suggests that problems with low DO are mainly restricted to the small lowland tributaries of the Waihou River. Monitoring at some of these sites indicates that DO concentrations can fall below the recommended limits for protection of fish populations during the summer low flow period. Within the main river, the failure of the DO logger at Te Aroha means there is still a gap in our knowledge of DO dynamics in the mid-lower reaches of the river. However, the longitudinal survey carried out during 2010 suggests that the data recorded at Gordon may be representative of conditions at Te Aroha and thus DO is maintained at a level sufficient for protection of fish communities under the flow conditions experienced in 2010. When compared to the long-term flow record at Okauia, 2010 was representative of an average year, with a minimum flow over the monitoring period of 20.4 $m^3 s^{-1}$ which is equivalent to 103% of the mean annual 1-day low flow (MALF). Data should be collected from Te Aroha to confirm the representativeness of the Gordon data. It may also be beneficial to extend the longitudinal survey further downstream in order to ensure the cumulative effects of additional discharges do not exceed the assimilative capacity of the river.

Analysis of the interaction between DO and flow showed no generalised correlation between the mean daily flow and daily DO minima across the range of summer low flows experienced during this study. However, the relationship between these variables is highly complex and governed by several different interacting factors e.g., temperature and antecedent conditions. It may therefore be beneficial to undertake a more in-depth analysis of the data to investigate these interactions and any time lags in effects that may occur.

In the main stem of the river, DO does not appear to be significant limiting for ecological communities. Consequently, if the degree of hydrological alteration is expected to be low, there may be little need to consider DO dynamics in the flow allocation process at the catchment scale unless it affects the assimilative capacity of the river. However, in the smaller tributaries where the aquatic communities are impacted by low DO concentrations it may still be necessary to take DO into account in making flow allocation decisions because of the combined effect of multiple stressors. Whilst DO may not always vary significantly directly with flow under low flow conditions, low flows do contribute towards creating the conditions most conducive to deterioration of DO in lowland streams. Low flows reduce water velocity, which impacts on stream mixing; increase water temperatures, subsequently reducing DO saturation capacity; encourage the proliferation of macrophytes by increasing the stability of substrates; allow encroachment of riparian vegetation, which can reduce re-aeration potential by covering the water surface; and will reduce the capacity of the stream to assimilate point and diffuse sources of pollution. Consequently, as the degree of hydrological alteration increases, the likelihood of impacts on the frequency, duration and/or timing of low flows may concurrently increase, and in the absence of appropriate mitigation (e.g., riparian planting), the likelihood of DO conditions deteriorating is increased. Higher protection levels should therefore be applied to the smaller lowland tributaries in order to account for the cumulative effects of multiple stressors in these systems and because they are important as long-term habitat for several native fish species.

5. Recommendations

- Extend the longitudinal DO survey downstream of Te Aroha to help identify potential cumulative effects in the lower reaches of the river. Support this with intensive DO monitoring at selected sites over the same reach where necessary.

- Apply precautionary protection levels (i.e., limited or no allocation) to account for the effect of multiple stressors in small lowland tributaries where DO is identified as a limiting factor on aquatic communities.

- Where assimilative capacity can be maintained, water from the main stem of the river can be allocated according to assessments of physical habitat and flow regime requirements.

- Where multiple stressors are acting to reduce DO concentrations, the potential for river restoration/rehabilitation to ‘free up’ more water for allocation should be investigated.

6. References

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