DOES A LARGE ON-LINE STORMWATER POND PUT THE HEAT ON THE DOWNSTREAM ENVIRONMENT

D. C. Miller - Freshwater Ecologist - Tonkin & Taylor, Hamilton

ABSTRACT

Increases in downstream water temperatures and potential effects on stream life as a result of on-line stormwater ponds is an issue that is currently receiving some attention. Most of the research experience on such temperature effects has been around existing small ponds with no New Zealand before and after case study examples.

CDL Land New Zealand Ltd (CDL) is developing a 74 ha residential subdivision in the growth area of Flagstaff in northern Hamilton. The development includes a large on-line stormwater detention pond (1.23 Ha) constructed over the bed of the main catchment stream. The project offered a valuable opportunity to gather water temperature data before and after lake construction.

Stream temperature data were collected from stream sites upstream and downstream of the lake footprint over two summer periods prior to lake construction and over two summer periods following construction. Monitoring captured likely worst case scenario conditions during the 2008 drought prior to the lake and the 2012/2013 drought post construction. The data show a clear increase in peak summer water temperatures in the downstream environment following lake construction. However, the frequency that effect thresholds for native stream fauna have been exceeded was less than anticipated.

KEYWORDS

On-line; ponds; temperature; Hamilton; fish; macroinvertebrates; water quality

PRESENTER PROFILE

Dean Miller is a senior freshwater scientist with Tonkin & Taylor in Hamilton. Dean's work includes fish passage assessment and design, water and habitat quality investigation, surveys of aquatic fauna and flora, design and implementation of monitoring programs and assessment of environmental effects for projects within and affecting aquatic environments.

1 INTRODUCTION

Increases in stream water temperatures as a result of discharges from on-line ponds is a well-documented issue (Maxted *et al*. 2005; Chung 2007; Galli 1990; Ham *et al*. 2006; Jones & Hunt 2010). Increases in stream temperatures as a result of discharges of heated water, termed thermal enrichment, can affect a wide range of biological and physical processes in receiving streams as well as cause direct stress and mortality in stream biota. This issue is currently receiving some attention with a recent report commissioned by Auckland Council addressing stormwater issues and management options associated with temperature as a contaminant (Young *et al*. 2013).

A review of available literature indicates that New Zealand research experience on such on-line pond temperature effects has comprised a study of existing small rural ponds (Maxted *et al*. 2005) and a study of existing urban stormwater ponds (Chung 2007), both in the Auckland region. There are no New Zealand case study examples available that examine how an on-line pond has changed stream temperature conditions compared to a pre-pond baseline scenario.

This paper presents the results of an in-stream temperature monitoring programme undertaken in an urban Hamilton stream over several summer periods between 2007 and 2013. The monitoring has captured one summer season prior and two summer seasons post the commissioning of a large on-line stormwater lake situated within a developing residential area. Monitoring has been undertaken in accordance with a draft Operations and Maintenance Plan developed for the lake and has included sites upstream and downstream of the lake footprint. A site located at the bottom end of a relatively well shaded reach of stream approximately 750 m downstream of the lake outlet was included to establish if a reduction in temperature occurred over that reach.

The key questions that the monitoring programme set out to answer with respect to stream temperatures, and that are addressed in this paper are as follows:

i. What effect does the lake have on the downstream temperature regime and to extent are effects criteria for stream biota exceeded?

ii. What is the extent of temperature effects in the downstream environment and how effective is riparian shading in reducing thermal enrichment?

2 MAGELLAN LAKE PROJECT BACKGROUND AND SETTING

2.1 THE PROJECT

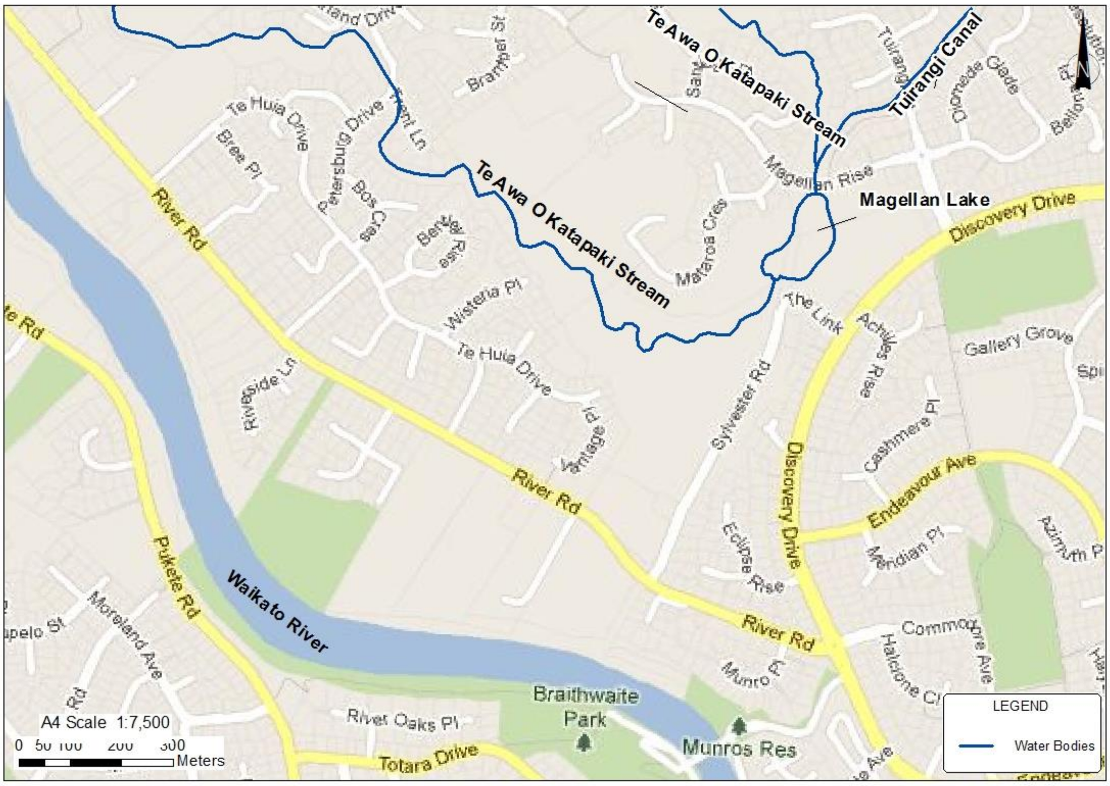
CDL is developing a 74 Ha residential subdivision located to the north of the existing Flagstaff urban area, in northern Hamilton. The development is situated within the Te Awa O Katapaki Stream catchment, a tributary of the Waikato River, and surrounds part of the main stream and its tributaries.

In order to manage stormwater from its land holding CDL has constructed a large stormwater detention pond over the bed of the Te Awa O Katapaki Stream. The pond is called “Magellan Lake” and its location is shown in Figure 1.

Tonkin & Taylor (T&T) has been working with CDL on the Magellan Lake project since 2001. T&T undertook hydrology, stormwater and ecological assessments that supported both the design of the lake and its outlet structure and the consent applications for the lakes construction and operation. T&T has also developed an Operations and Maintenance Plan (O&MP) for the lake and has undertaken the environmental monitoring programme detailed in O&MP since consents were granted in December 2008.

The lake was constructed over the 2009/10 earthworks season with the lake and outlet structure being operational by August 2010.

Figure 1: Location of Magellan Lake within the developing residential area of northern Flagstaff



2.2 CATCHMENT DESCRIPTION

The Te Awa O Katapaki Stream catchment covers a total area of about 687ha of which around 50% (336 ha) lies upstream of the CDL development.

Stormwater from the catchment is conveyed to the lake via two main sources. An open man-made stormwater canal, known as the Tuirangi Canal, flows in a southwesterly direction through the CDL's subdivision area to the northern end of Magellan Lake (see Figure 1). This canal receives stormwater from the bulk of the total CDL land area located to the north and east of the lake. The canal also conveys water from land not owned by CDL in the north eastern area of the catchment.

Another open drain (the upper Te Awa O Katapaki Stream) collects stormwater runoff from the north western part of the catchment. This drain joins the Tuirangi Canal a short distance upstream of the Magellan Rise culvert and the northern end of Magellan Lake (see Figure 1).

The upper catchment water courses have been highly modified as a result of agricultural land use practices and then subsequently by urban development. A major change has been the diversion of most of the upper catchment flows out of the Te Awa O Katapaki Stream channel and into the Tuirangi Canal. Base flows in the Te Awa O Katapaki stream are now negligible (<1 L/s). Base flows in the Tuirangi Canal are around 10-15 L/s and this is thought to be partially made up of groundwater seeping into large butt jointed stormwater pipes in the upper residential catchment.

Magellan Lake discharges via a combined outlet and eel pass structure to a stilling basin before flows enter the lower Te Awa O Katapaki Stream. An 1800 mm diameter stormwater pipe conveys groundwater seepage and stormwater from the south eastern part of the catchment and discharges to the eastern side of the stilling basin. Base flows from the stormwater pipe are around 20 L/s. Early in the design process it was considered diverting this flow into Magellan Lake to assist with lake flushing rates. However, the low level of the pipe made this unfeasible as the excavation required to build the lake would have needed to be significantly deeper.

Downstream of Magellan Lake and to the Waikato River (3 km from Magellan Lake) the Te Awa O Katapaki Stream flows through an incised and vegetated gully. Land use comprises newly developed residential areas on both banks for around half of its length with agricultural land use and a golf course in the lower catchment. The lower stream includes a second smaller on-line stormwater pond located around halfway between Magellan Lake and the Waikato River.

2.3 MAGELLAN LAKE DESCRIPTION

Magellan Lake was primarily developed to provide stormwater detention and treatment for CDL's landholding but has been oversized in this respect and has additional detention and treatment capacity. A secondary objective of Magellan Lake is to provide amenity value and the lake reserve includes a walkway and reserve areas for passive recreation.

In terms of its stormwater function, Magellan Lake is a wet pond stormwater attenuation and treatment system and has a normal operating level of RL 25.8 (with a footprint area of around 1.23 ha). The average depth is about 2 m. The lake is approximately crescent shaped and has hard edges formed by 0.9 m retaining walls with a narrow (1.0m) and shallow (0.3 -0.4 m) safety bench around the lake edge.

2.4 DOWNSTREAM RECEIVING ENVIRONMENT DESCRIPTION

Downstream of Magellan Lake the stream meanders through vegetated gully system known as the Te Awa O Katapaki Esplanade. Riparian vegetation in this area consists of a dense canopy of mainly exotic trees (grey willow) with some native trees and shrubs. Shade levels would generally be higher in spring and summer relative to autumn and winter when grey willow trees lose their leaves.

The stream is generally incised between steep banks and dominated by soft bottom substrates. There is good aquatic habitat complexity, mainly as a result of willow branches and roots in and adjacent the stream. Habitats include the occasional woody riffle, chutes, abundant deep pools (between 0.5 m to 1 m in depth), backwater pools and moderately fast and slow flowing runs. Woody debris cover, comprising of mainly living and dead grey willow branches, is abundant and forms bank overhangs and in-stream woody weirs. Undercut banks are common and living and dead tree branches can provide dense in-stream cover.

Macroinvertebrate sampling was recently undertaken by Hamilton City Council at four sites on the lower stream (Miller *et al*. 2013a). Sensitive mayfly, stonefly and caddisfly taxa were generally absent from samples and Macroinvertebrate Community Index scores were indicative of reduced habitat quality conditions (60 -80).

The lower stream supports a moderate diversity of native fish species with records for shortfin eels (*Anguilla australis*), longfin eels (*Anguilla dieffenbachii*), common smelt

(*Retropinna retropinna*), inanga (*Galaxias maculatus*), common bully (*Gobiomorphus cotidianus*) and giant kokopu (*Galaxias argenteus*) (Aldridge & Hicks 2006; Miller 2013b). Longfin eel and giant kokopu are classified as At Risk: gradual decline (Allibone *et al*. 2010). Mosquito fish (*Gambusia affinis*) (pest species) have also been recorded.

3 BACKGROUND TO THE TEMPERATURE ISSUE AND MONITORING PROGRAMME

3.1 PREDICTED TEMPERATURE CONDITIONS AND EFFECTS

The potential for Magellan Lake to result in elevated downstream temperatures was identified in T&T's earliest ecological assessment of the site and the lake proposal (T&T 2005). Hamilton City Council (HCC), the Department of Conservation and Waikato Regional Council (WRC) also expressed concerns as the stream had recently been found to support giant kokopu, an at risk species. A more detailed assessment of likely summer temperature ranges and maximums in the lake and in the downstream reach as a result of the lake discharge was undertaken (T&T 2007).

The assessment was made based on the best available information at the time. This included available data for on-line shallow ponds in the Auckland Region (Maxted *et al*. 2005) and somewhat dated information on lakes in the northern Hamilton area (Boswell, 1985).

3.1.1 LAKE TEMPERATURES

A review of the above studies suggested that peak shallow lake temperatures in the Waikato and in small on-line rural ponds in Auckland could reach 25.5 to 28.5 °C. The discharge from Magellan Lake was to be over the surface of a weir embankment and was predicted to reach peak temperatures within this range.

3.1.2 STREAM TEMPERATURE CONDITIONS AT THE OUTLET

In terms of effects on downstream ecology, the effects of elevated temperatures in the lake discharge were considered to depend on whether downstream temperatures would be raised above the tolerance levels of in-stream fauna, and the frequency with which that occurred. In their review of New Zealand Literature, Maxted, *et al.* (2005) estimated that slight adverse effects on native fish and macroinvertebrates occurred at temperatures above 22 °C and moderate effects occurred at temperatures above 24 °C. This was roughly consistent with standard guideline that water should be less than 25 °C between October and April for most native fish.

Using stream temperature data collected downstream of small rural on-line ponds, Maxted *et al.* (2005) determined that the critical summer period in terms of the effects on downstream temperatures was a 40 day period between mid to late January and the beginning of March. Over this period only three out of the 6 ponds monitored in that study exceeded the moderate adverse effects criteria of 24 °C. On average these three ponds exceeded the 24 °C criteria on about 15 days over the 40 day critical period.

Based on the available data it was predicted that the moderate adverse effects temperature threshold of 24 °C for native fauna could potentially be exceeded downstream of Magellan lake during peak summer conditions and that this might occur on about 15 days over the middle of summer (T&T 2007).

3.1.3 EXTENT OF DOWNSTREAM TEMPERATURE EFFECTS

The downstream extent of temperature effects and the rate of cooling was also predicted based on available literature. Although not quantified in terms of any variable factors such as riparian shade, the work of Maxted *et al*. (2005) suggested a rate of downstream cooling of 1 °C per 100 m is possible. Nomographs in Collier, *et al*. (1995) however, suggest that over 1 km of moderate shading may be required to mitigate elevated temperature effects in small streams.

CDL own the land surrounding the stream to a point approximately 750 m downstream of the Magellan Lake outlet. This bulk of this reach is subject to high levels of riparian shade and it was predicted that effect of the lake on stream temperatures would be unlikely to extend beyond that point. Riparian planting to improve shade levels in the long term between the outlet and where the existing shaded reach was proposed to assist in reducing stream temperatures.

3.1.4 MONITORING PROGRAMME

Consents for the lake were granted in late 2008, although there was some remaining uncertainty around the predicted effects. This uncertainty lead to the offer of a monitoring programme by CDL and the inclusion of pre and post lake temperature monitoring in the draft O&MP for the lake. The monitoring programme aimed to establish baseline temperature conditions in the Te Awa O Katapaki stream prior to lake construction and then to establish the actual effects of the lake following commissioning.

4 METHODS

The temperature monitoring programme comprised the collection of continuous temperature data from sites upstream and downstream of the proposed lake over one summer period prior to lake construction (baseline data), and two summer periods following lake commissioning. Monitoring was undertaken during summer conditions only when the potential for any effects of the lake on downstream temperature would be highest.

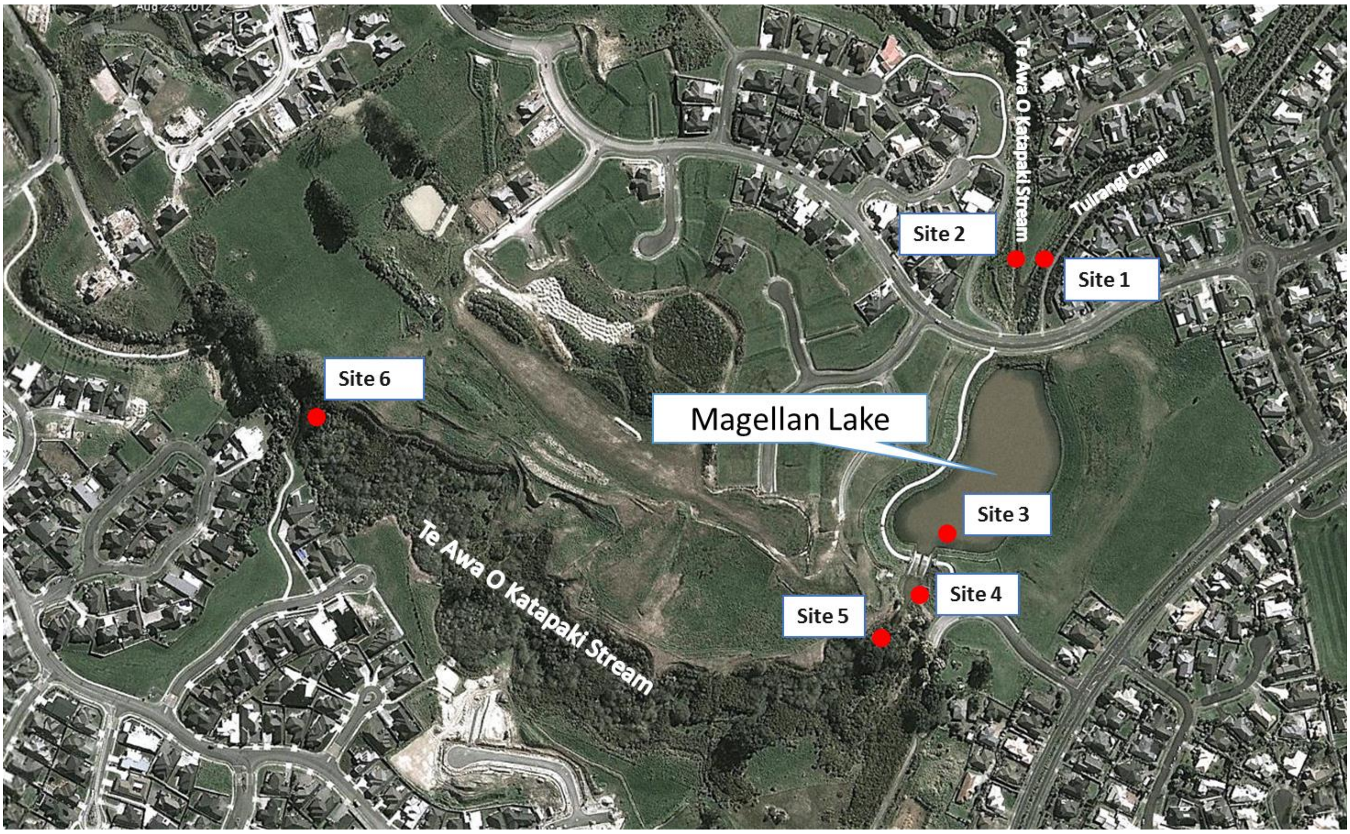
4.1 MONITORING SITES

Monitoring sites are described in Table 1 below and shown on Figure 3. Sites 1, 2, 5 and 6 were located at similar sites prior to and following construction of the lake. Sites 3 and 4 were added to the monitoring programme once the lake was operational.

Table 1: Magellan Lake temperature monitoring site locations

Site	Site description	GPS Coordinates (NZTM)
1	The Tuirangi Canal immediately upstream of the lake.	1798276 E 5822078 N
2	Te Awa O Katapaki Stream immediately upstream of the lake.	1798249 E 5822083 N
3	Magellan Lake near the service outlet.	1798229 E 5821820 N
4	The 1800 diameter pipe inflow to stilling basin.	1798211 E 5821803 N
5	Te Awa O Katapaki Stream immediately downstream of the lake.	1798152 E 5821759 N
6	The Te Awa O Katapaki Stream 750 m downstream of the lake.	1797637 E 5821971 N

Figure 2: Magellan Lake temperature monitoring sites. Aerial photo sourced from Google Earth (Copyright: 2014)



4.2 TEMPERATURE MONITORING

Continuous water temperature data was collected at the various locations described in Table 1 over several summer periods since 2007. Water temperature monitoring periods are summarised in Table 2.

Table 2: Temperature monitoring periods

Summer		Sites monitored	Logger deployment date	Logger retrieval date
2007/08	Pre-lake	1, 2, 5, and 6	21 December 2007	22 April 2008
2009	Pre-lake	1, 4 and 5	4 February 2009	5 March 2009
2009/2010*	Pre-lake	1, 2, 5 and 6	23 December 2009	30 April 2010
2012	Post lake	1, 2, 3, 4, 5 and 6	9 January 2012	30 April 2012
2013	Post lake	1, 2, 3, 4, 5 and 6	9 January 2013	30 April 2013

*Some loggers were lost as a result of in-stream earthworks resulting in loss of some data and gaps in the continuous record as available loggers had to be re-deployed.

Some of the data sets are incomplete due to a range of factors including loggers being buried beneath earthworks or being out of the water for part of the deployment period. The most comprehensive datasets are for the 2008 (pre-lake) summer period and the 2012 and 2013 post lake summer periods. The 2008 and 2013 monitoring periods captured pre-lake and post-lake drought conditions respectively. These data therefore likely represent worst case water temperature and dissolved oxygen scenarios prior to and post the construction of Magellan Lake and have been the focus of the data analysis.

All water temperature data were collected using Onset Tidbit v2 Temp loggers (Onset HOBOware pro computer applications; factory calibrated, accuracy ± 0.2°C over 0 to 50°C). Loggers were programmed to record temperature at 15 minute intervals.

Loggers were mounted to the inside of a 100mm sleeve of perforated PVC piping. A metal stake was driven into the stream bed at each site with a logger and associated PVC sleeve attached at approximately 200mm below water surface.

4.3 TEMPERATURE EFFECTS CRITERIA AND DATA ANALYSIS

4.3.1 EFFECTS CRITERIA

Our original predictions for temperature effects and then our assessments of conditions pre and post-lake were made using the temperature effects criteria presented in Maxted *et al*. (2005) who reviewed temperature criteria for New Zealand aquatic fauna as part of a study of their effects of ponds on stream water quality. They determined that adverse effects occur at surface water temperatures above 22 °C, 24°C and 26°C, corresponding to slight, moderate and severe effects respectively. Further work on the development of water temperature criteria for New Zealand stream fauna has been undertaken since the work of Maxted *et al*. (2005) and our original assessments for Magellan Lake.

A comprehensive review of all available thermal tolerance information for New Zealand biota was recently commissioned by Auckland Council, Waikato Regional Council and Hawkes Bay Regional Council (Olsen *et al*. 2012). The authors developed acute and chronic thermal criteria for a range of native species but stressed that the values are interim due to limited thermal tolerance information being available. It was concluded that maximum temperatures in upland streams that are less than 20°C should protect even the most sensitive native taxa. In comparison, the most sensitive native taxa in lowland streams should be protected as long as maximum temperatures are less than 25°C. The selection of the appropriate criteria depends on the mean summer temperature of the watercourse in question. The 20 °C mean temperature criterion would apply at a mean summer temperature of 15 °C and the 25°C criterion where mean summer temperature was around 20 °C (Olsen *et al*. 2012).

Further work by Young *et al.* (2013) was undertaken to apply an Auckland regional context to the criteria developed by Olsen *et al*. (2012). Young *et al.* (2013) considered that there was too much uncertainty around the 25°C criterion for lowland waterways. They recommended that more conservative temperature criterion of 20°C be applied to all streams where the protection of stream values, in particular those related to the ecology and connectivity of streams, are of management concern.

We note that further to the above, a design effluent quality requirement (DEQR) for temperature has also been included in the stormwater management provisions of the Unitary Plan (Auckland Council 2013). The Unitary Plan adopts a temperature DEQR of 25°C for discharges to a river or stream. This allows for runoff from impervious surfaces without the need to treat. Wet ponds are regarded as non-compliant with this threshold on the basis that there is substantial evidence that they routinely discharge at temperatures up to 30 °C.

Mean summer stream temperatures in the Te Awa O Katapaki Stream at the location of the Magellan Lake outlet were between 17 and 18 °C prior to the lake and around 20 °C following the lakes construction. Based on that data and that the stream is a lowland watercourse the selection of the 25°C criterion in Olsen *et al*. (2012) may be appropriate. For our assessment of Magellan Lake temperature data we have selected to use the criteria developed by Maxted *et al.* (2005) as these are more conservative.

4.3.2 DATA ANALYSIS

Data analysis has focussed on Sites 1, 3, 5 and 6 located on the main surface water inflow into the lake (the Tuirangi Canal), the lake near the outlet, the Te Awa O Katapaki Stream downstream of the lake outlet and 750 m downstream of the lake outlet respectively.

Site 4 on the Upper Te Awa O Katapaki Stream has been omitted as this watercourse contributes negligible base flow to the system (<1 L/s). Data from Site 4, the 1800 stormwater pipe that discharges to the stilling basin downstream of the lake outlet is only briefly summarised. This pipe discharges groundwater seepage as base flow (around 15 L/s).

Data are presented for the months of January to March inclusive as these are the warmest months of the year.

Our analysis of the temperature data has been fairly simple and has involved a comparison of the continuous temperature monitoring summary statistics with the thresholds for slight, moderate and severe effects of 22 ^{O}C, 24^{O}C and 26^{O}C respectively following Maxted *et al.* (2005).

5 RESULTS

5.1 LAKE DISCHARGE TEMPERATURES

Water temperature data was collected from a site within the lake over the 2012 and 2013 summer periods (Site 3). Data were collected from around 0.2 m below the surface and are considered to be representative of the temperature of water discharging from the lake. 2012 and 2013 data are presented on Figures 3 and 4 respectively.

Lake temperatures are indicated to be relatively high compared to stream temperatures and also in comparison to temperature criteria. The plots show that 2013 was much warmer compared to 2012 conditions.

Figure 3: Summary plot of 2012 summer temperature monitoring data for Magellan Lake at Site 3

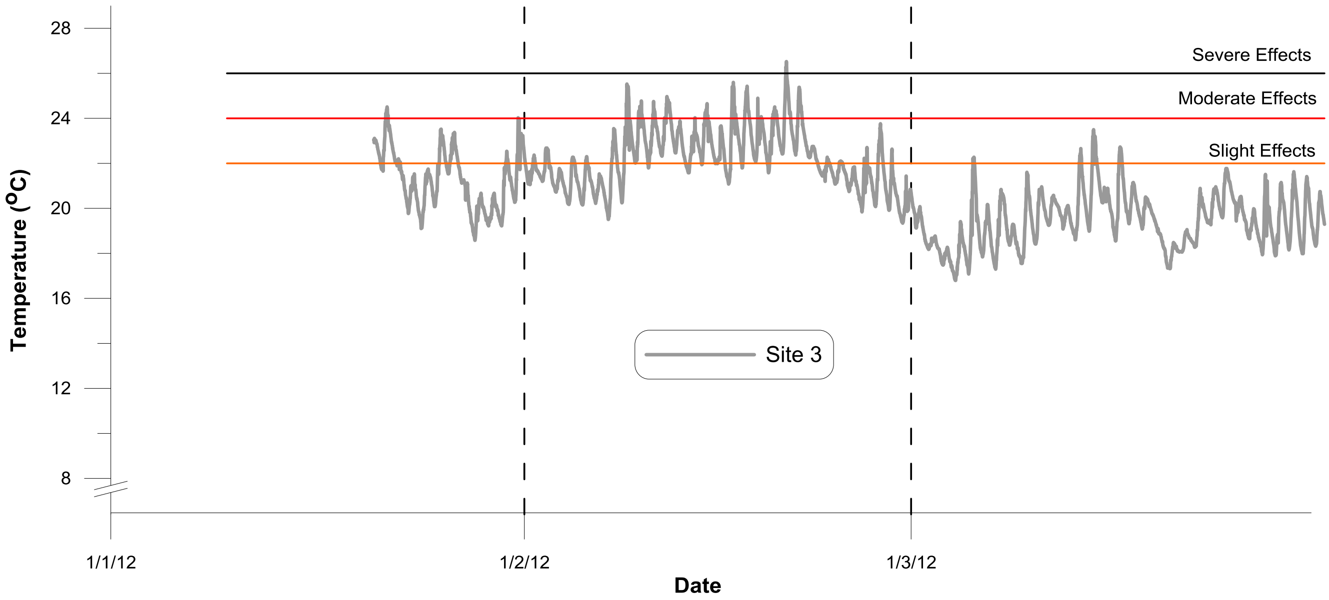
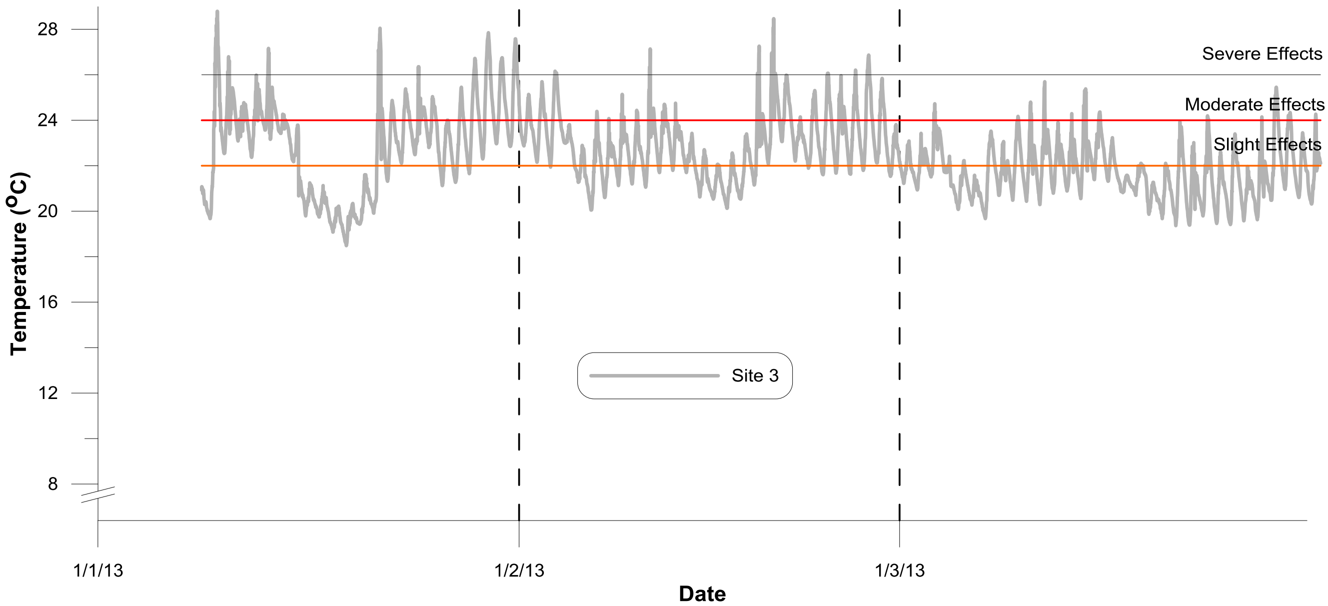


Figure 4: Summary plot of 2013 summer temperature monitoring data for Magellan Lake at Site 3



5.2 STREAM TEMPERATURES

Summary plots showing temperature data collected over the 2008, 2012 and 2013 summer seasons are included as Figures 5, 6 and 7 respectively. The plots display data collected from Sites 1, 5 and 6 along with effects criteria as appropriate.

Figures 5, 6 and 7 show that the warmest conditions and most exceedances of temperature thresholds at stream sites generally occur in January and February, with relatively high temperatures recorded in March 2013 also. A visual comparison of the temperature plots alone indicates that conditions were generally warmer in the downstream reach of the Te Awa O Katapaki Stream following commissioning of the lake while conditions upstream remained similar each summer period. Conditions also appear warmer in general in 2013 compared to 2012.

Figure 7 indicates that temperatures were generally cooler at Site 6 relative to Site 5 in 2013 suggesting that some cooling occurs through the shaded reach downstream of Magellan Lake.

Figure 5: Summary plot of 2008 summer temperature monitoring data

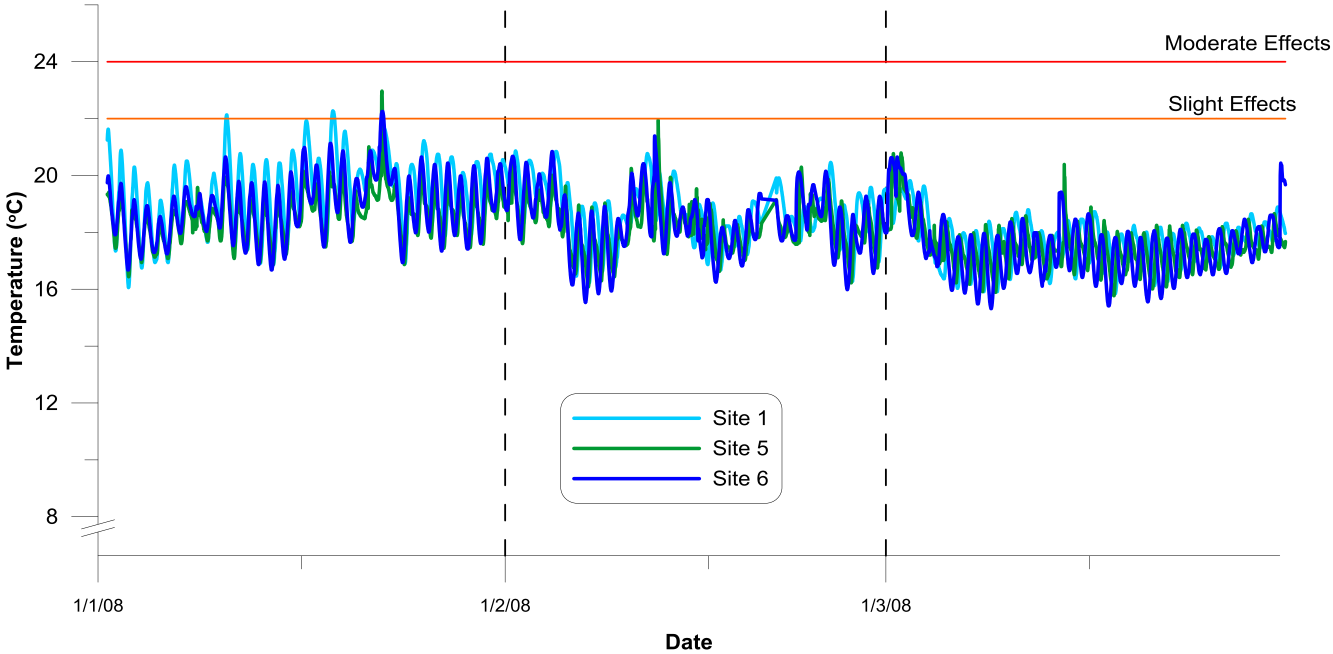


Figure 6: Summary plot of 2012 summer temperature monitoring data

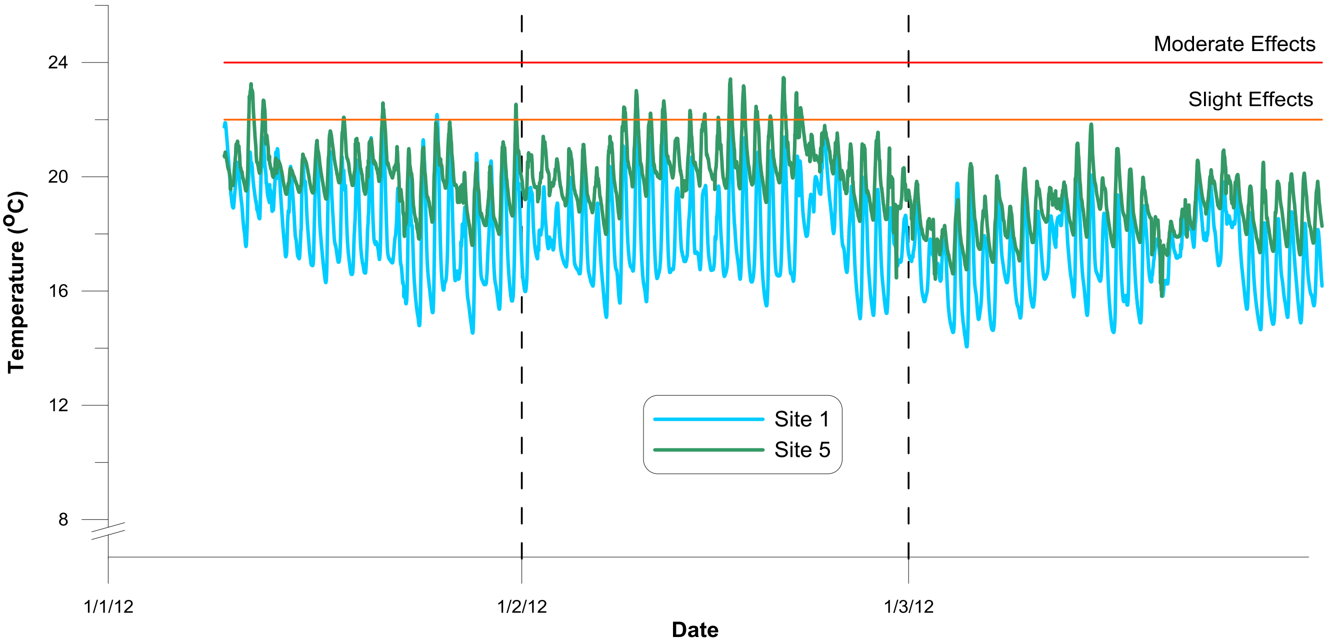
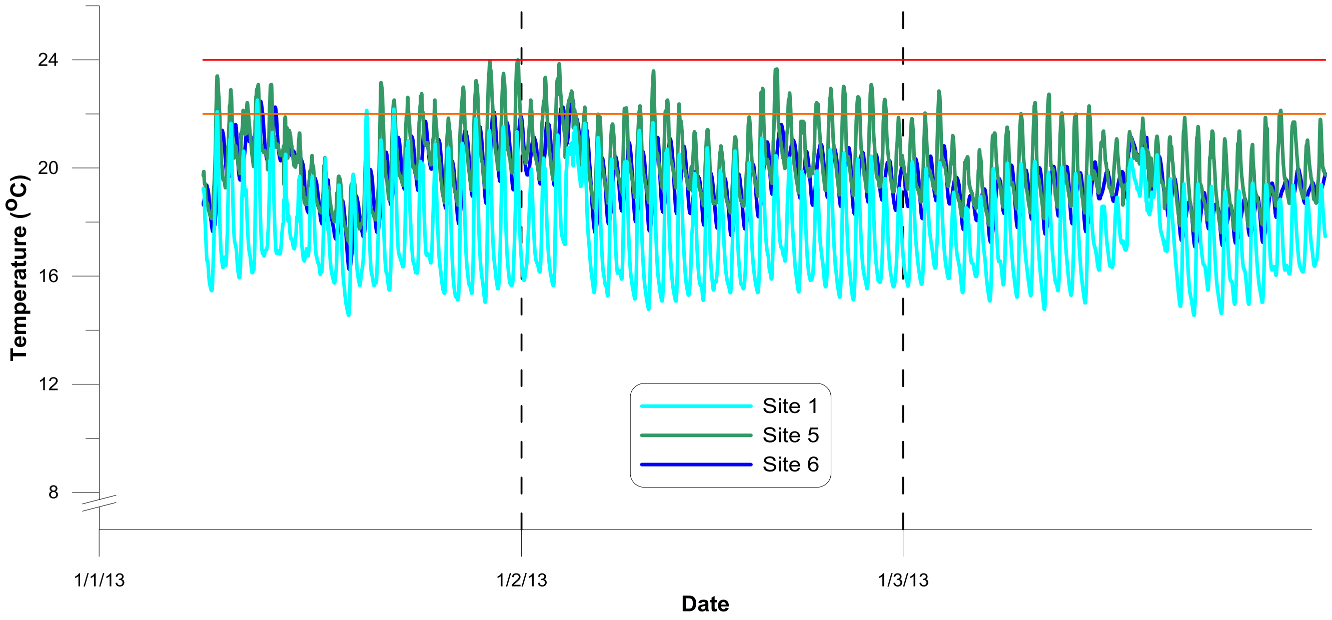


Figure 7: Summary plot of 2013 summer temperature monitoring data



5.3 COMPARATIVE SUMMARY STATISTICS AND EFFECTS CRITERIA EXCEEDANCES AT STREAM SITES

Comparative statistics for the 2007/08 pre-lake and 2012 and 2013 post lake monitoring seasons at Sites 1, 5 and 6 are summarised in Table 3. Data are summarised for each of the three warmest summer months, being January, February and March. Assessments against temperature criteria have been made based on the percentage of measurements (roughly equating to the percentage of time) that criteria were exceeded and the number of days that the criteria were exceeded.

Key points to note from the summary data in Table 3 are as follows:

- Temperatures at Site 1, upstream of Magellan Lake remained fairly stable between monitoring years with warmest conditions occurring in January, including some exceedance of the slight effects criterion. Maximum temperatures, mean diel range and the amount of exceedances of the slight effects criterion point to conditions being slightly warmer in 2012 and 2013 compared to 2008.

- A comparison of the maximum monthly temperature recorded at Sites 1 and 5 (upstream and downstream of the lake respectively) indicates that maximum temperatures were higher downstream of the lake by around 1 to 2 °C. Although the biggest difference occurred in January 2008, prior to the construction of the lake.

- Maximum water temperature at Site 5 was 1°C higher in January 2013 compared to 2008 and 2°C higher in February and March 2013 compared to February and March 2008.

Table 3: Temperature monitoring summary statistics for data collected in 2008, 2012 and 2013 from Sites 1, 5 and 6

Month	Site	Year	Temp (°C)			% measurements that exceed criterion				Number of days that exceed criterion			
			Min.	Max.	Mean diel range (±95%CI)	n	Temp. criterion			n	Temp. criterion		
							>22	>24	>26		>22	>24	>26
Jan	1	2008	14.4	21.1	4.0 (± 0.6)	2976	1.04	0.0	0.0	31	2	0	0
		2012	14.5	22.3	4.3 (± 0.2)	2128	0.61	0.0	0.0	22	2	0	0
		2013	14.6	22.5	5.1 (± 0.2)	2239	1.16	0.0	0.0	23	4	0	0
	5	2008	16.4	23.0	2.0 (± 0.2)	2976	0.2	0.0	0.0	31	1	0	0
		2012	17.6	23.3	2.3 (± 0.1)	2128	4.14	0.0	0.0	22	5	0	0
		2013	17.3	24.0	3.3 (± 0.2)	2239	15.2	0.04	0.0	23	15	1	0
	6	2008	16.7	22.3	2.3 (± 0.2)	2976	0.6	0.0	0.0	31	1	0	0
		2013	16.2	22.5	2.3 (± 0.1)	2239	2.28	0.0	0.0	23	4	0	0
Feb	1	2008	16.2	20.9	1.9 (± 0.2)	2677	0.0	0.0	0.0	29	0	0	0
		2012	15.0	22.4	3.9 (± 0.2)	2784	0.36	0.0	0.0	29	1	0	0
		2013	14.8	21.7	4.9 (± 0.1)	2688	0.0	0.0	0.0	28	0	0	0
	5	2008	16.1	21.9	1.9 (± 0.3)	2677	0.0	0.0	0.0	29	0	0	0
		2012	16.5	23.5	2.6 (± 0.1)	2784	7.7	0.0	0.0	29	14	0	0
		2013	18.3	23.9	3.2 (± 0.1)	2688	15.7	0.0	0.0	28	19	0	0
	6	2008	15.5	21.4	2.1 (± 0.3)	2677	0.0	0.0	0.0	29	0	0	0
		2013	17.5	22.5	2.3 (± 0.1)	2688	2.1	0.0	0.0	28	2	0	0
Mar	1	2008	15.8	19.8	1.6 (± 0.2)	2976	0.0	0.0	0.0	31	0	0	0
		2012	14.1	20.7	3.3 (± 0.2)	2976	0.0	0.0	0.0	31	0	0	0
		2013	14.6	20.7	3.8 (± 0.1)	2976	0.0	0.0	0.0	31	0	0	0
	5	2008	15.8	20.8	1.9 (± 0.2)	2976	0.0	0.0	0.0	31	0	0	0
		2012	15.8	21.8	2.3 (± 0.1)	2976	0.0	0.0	0.0	31	0	0	0
		2013	17.6	22.8	3.1 (± 0.1)	2976	2.25	0.0	0.0	31	8	0	0
	6	2008	15.3	20.7	2.0 (± 0.3)	2976	0.0	0.0	0.0	31	0	0	0
		2013	17.1	21.1	1.7 (± 0.1)	2976	0.0	0.0	0.0	31	0	0	0

- Maximum water temperature at Site 6 was slightly cooler in January 2013 compared to January 2008 but around 1°C higher in February 2013 compared to February 2008.

- The mean diel range in water temperature was greater in January, February and March 2013 relative to January, February and March in 2008 for Sites 1(upstream of the lake) and Site 5 (downstream of the lake) but was similar between years at Site 6.

- Minimum temperatures were higher by 1 or 2 °C at both Sites 5 and 6 in 2013 relative to 2008 for all months.
- The percentage of measurements (and therefore time) above the 22 °C slight effects criterion at Site 5 was near or at zero in January and February 2008 and 15 % in January and February 2013. The 22 °C slight effects criterion was exceeded by 2.25 % of measurements at Site 5 in March 2013 compared to zero in March 2008.
- The moderate effects threshold of 24 °C was exceeded on 0.04% of measurements at Site 5 in January 2013. This was the only stream site where an exceedance of the moderate effects threshold was recorded.
- The number of days where the 22 °C slight effects criterion was exceeded at Site 5 was higher in all months in 2013 compared to 2008.

5.4 UPSTREAM TO DOWNSTREAM TRENDS

5.4.1 MEAN TEMPERATURES

Peak stream temperatures and assessment against temperature criteria for biota are important in terms of assessing effects. However, a general appreciation changes in temperatures from upstream to downstream and the pre and post lake can be gained by inspection of mean temperature conditions. Table 4 shows mean temperatures recorded over the summer months in 2008 and 2013. Note that Sites 3 and 4 were not added to the monitoring programme until after the lake was constructed.

Table 4: Mean temperatures at Magellan Lake monitoring sites over the 2008 and 2013 summer period (all units °C)

Month	Site 1	Site 3	Site 4	Site 5	Site 6
January 2008	19.4	-	-	18.6	18.9
January 2013	17.7	22.9	17.4	20.4	19.8
February 2008	18.7	-	-	18.2	18.4
February 2013	17.5	23.0	17.9	20.6	19.7
March 2008	17.7	-	-	17.5	17.5
March 2013	17.3	21.7	17.8	19.8	19.0

In terms of before and after lake comparisons the key observations are in regard to Sites 5 and 6. For site 5 post lake mean temperatures are around 2 to 2.3 °C warmer in the 2013 data. For Site 6 the difference is around 1 to 1.5 2.3 °C.

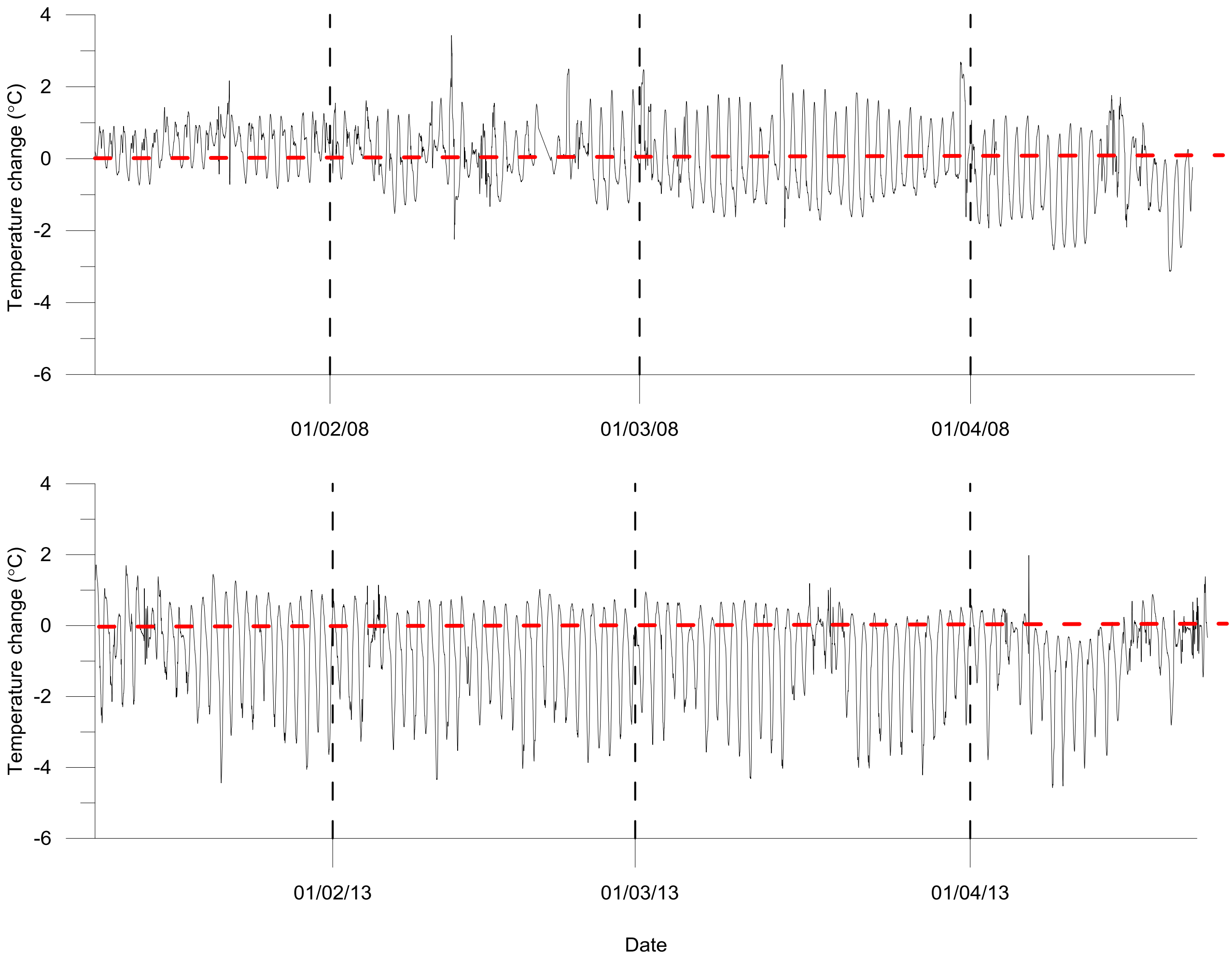
In terms of upstream to downstream trends, mean temperatures in 2008 were generally highest Site 1 (upstream of the lake footprint) and then were cooler at sites downstream of the lake footprint, but with a slight increase from Site 5 to Site 6. The opposite trend is observed in the 2013 data with cooler mean temperatures at Site 1, comparatively high mean temperatures at Site 5 and then cooler by 0.6 to 0.9 °C at Site 6. Note that mean temperature conditions were cool and remain fairly similar through the summer months at Site 4. This site was located on the 1800 mm stormwater pipe that discharges to the stilling basin and mixes with water discharged from the lake upstream of Site 5.

In the post lake scenario the broad upstream to downstream trend based on mean temperatures appear to be as follows. The lake results in an increase in temperature of up to 5 °C. This then cools by around 2 °C by Site 5 when mixed with the cooler water entering the stilling basin at Site 4. Further cooling then occurs through the shaded reach of the stream to Site 6 (0.6 to 0.9 °C).

5.4.2 DOWNSTREAM COOLING

The extent of water cooling through the well shaded reach of the stream from Site 5 to Site 6 was further examined by plotting the difference of paired temperature measurements for the two sites (i.e. the change in temperature with progression downstream from Site 5 to Site 6). Plots of paired data for 2008 and 2013 are shown in Figure 8 below. Data below zero indicate a temperature decrease from Site 5 to Site 6 and data above zero indicate an increase. Summary statistics for the data presented on Figure 8 are included in Table 5.

Figure 8: Plots showing the difference in paired temperature measurements between Sites 5 and 6. Data below zero indicate a temperature decrease from Site 5 to Site 6 and data above zero indicate an increase.



The 2008 data presented on Figure 6 shows a diurnal cycle in the temperature change from Site 5 to Site 6 with the data spread around the zero change line. This trend is also reflected in the average temperature difference between Sites 5 and 6 of zero for the 2008 data. So in 2008 Site 6 was cooler than Site 5 for around half the time and vice versa.

A diurnal pattern in the temperature change is also shown in the 2013 data, although the plot shows a higher percentage of time where Site 6 is cooler than Site 5 when compared to 2008. This is reflected in an average temperature reduction from Site 5 to 6 of 0.8 °C and that 68.5% of paired measurements are cooler at Site 6 (see Table 5). A closer inspection of the temperature plot for 2013 (Figure 7) indicates that there is a time lag between Site 5 and 6 in terms of when peak daily temperature occurs. Peak temperatures generally occurred in the late afternoon and evening at Site 5 (3 to 6 pm) and then later at Site 6 (anywhere between 7 pm and 2 am).

Table 5: Summary statistics for water temperature change between Sites 5 and 6 over the period January 10 to April 22 for 2008 and 2013 (all units °C)

Year	**2008**	**2013**
Number of measurements	9763	9888
Highest temperature increase from Site 5 to Site 6	3.4	2.0
Highest temperature decrease from Site 5 to Site 6	3.1	4.6
Mean temperature difference between Sites 5 and 6	0.0	- 0.8
% of paired measurements where Site 6 is cooler than Site 5	46.9	68.5
% of paired measurements where Site 6 is warmer than Site 5	51.9	30.2

6 DISCUSSION

6.1 LAKE TEMPERATURE

Increases in stream water temperatures as a result of discharges from on-line ponds is a well-documented issue (Maxted *et al*. 2005; Chung 2007; Galli 1990; Ham *et al*. 2006; Jones & Hunt 2010). Temperature increases predominantly occur as result of incoming solar radiation, combined with extended detention and low levels of shade (Young et al. 2013). The permanent pool acts as a heat sink as incoming solar radiation heats water above the temperature of ambient air (Kieser 2004).

Temperature of water leaving Magellan Lake is relatively high compared to upstream conditions. In terms of mean temperatures the lake appears to result in a 5 °C increase compared to incoming stream flows over the summer months. Near surface water temperature monitoring collected from Magellan Lake near the outlet over the 2012 and 2013 summer periods recorded peak temperatures of 26.5 °C in February 2012 and 28.8 °C in January 2013. While these peak temperatures are relatively high, they are similar to predictions made through consent process for the lake (25.5 to 28.5 °C) which were based on available data for shallow lakes in the Auckland Region (Maxted *et al*. 2005) and information on natural shallow lakes in the northern Hamilton area (Boswell, 1985).

Post lake monitoring data have shown that in lake surface water temperature conditions are regularly elevated above moderate temperature effects criteria for native fauna (24 °C) and above the severe effects criteria (26 °C) on some occasions.

6.2 EFFECTS ON STREAM TEMPERATURE

The most comprehensive temperature monitoring datasets were obtained over the 2008 and 2013 summer periods, both of which were well documented droughts in the Waikato Region. The summer of 2008 was extremely dry with low levels of rainfall recorded at the Ruakura monitoring station (roughly 8 km from the site) over the January to March 2008 monitoring period (a total of 45 mm). The January to March 2013 period was almost as dry with only 50 mm total rainfall recorded. Stream levels were low over both monitoring periods and with low volume streams being generally heated and cooled more readily (Collier et al. 1995), the peak temperature data are likely to reflect worst case conditions for both the pre-lake and post-lake scenario.

The pre and post lake stream monitoring data show a clear increase in temperature conditions in the Te Awa O Katapaki Stream in the post lake scenario. This is attributable to heating within Magellan Lake as discussed in Section 6.1 above. Mean and peak temperatures recorded in the stream downstream of the lake are higher in the post lake scenario by around 1 to 3 °C. In terms of effects on downstream ecology, the effects of elevated temperatures depend on whether the discharge raises downstream temperatures above the tolerance levels of in-stream fauna and the frequency with which that occurs.

T&T's assessment of likely discharge temperatures during the consent process (T&T, 2007) suggested that the moderate adverse effects temperature criteria for native fauna of 24 °C could potentially be exceeded during peak summer conditions as a result of the lake. Data for other on-line ponds (Maxted *et al.* 2005) suggested that this might occur on about 15 days over the middle of summer.

The water temperature monitoring data (presented in Sections 5.1 and 5.2) has shown that the moderate adverse effects temperature threshold for native fauna of 24 °C was exceeded on one occasion only in the stream downstream of the lake (Site 5) in January 2013. This is less than the anticipated frequency of exceedance in the assessments undertaken through the consent process. However, the amount of time the slight effects criteria of 22 °C is exceeded at Site 5 does appear to have increased by up to 15% relative to pre-lake conditions.

The decision not to divert the flows from the 1800 mm diameter stormwater pipe into the lake has during the design process is likely to have assisted in mitigating for elevated temperatures in the discharge from the lake. This pipe contributes around 8 to 15 L/s of mainly groundwater seepage under base flow conditions (T&T in prep) and is relatively cool (see Section 5.4.1). This compares to around 14 to 17 L/s of warmer water discharged from Magellan Lake. The two flows are mixed in the stilling basin immediately downstream of the Magellan Lake weir and outlet structure and the temperature of the combined flow is represented by data for Site 5. Based on mean temperature data groundwater flow appears to result in a reduction of around 2 °C.

6.3 DOWNSTREAM COOLING

T&T's assessment of the likely extent of downstream effects during the consent process suggested that a reduction in water temperature to below temperature criteria could be achieved by between 250 to 750 m downstream of the lake outlet as a result of high levels of riparian shading (T&T 2007).

Temperature monitoring data 6 has shown that average summer water temperatures were similar at Sites 5 and 6 prior to the lake (in 2008). In the post lake scenario Site 6 was 0.8 °C cooler on average compared to Site 5 (2013 data). The cooling effect of the well shaded reach seems have arisen since the lake was installed and temperature conditions were elevated. Overall the data suggest that shading over the 750 m reach between Sites 5 and 6 is going part of the way to mitigating lake temperature effects. Improved shading in the reach immediately downstream of the lake as the riparian planting develops and further planting to shade the stilling basin may assist this process further.

7 CONCLUSION

This paper has presented and discussed the results of stream temperature monitoring programme undertaken at sites on the Te Awa O Katapaki Stream in northern Hamilton before and after the installation of a large on-line stormwater detention lake. Monitoring has captured summer drought and likely worst case temperature conditions prior to the lakes construction in 2008 and post construction in 2013.

The data show relatively clearly that the lake has resulted in an increase in mean and peak summer water stream temperatures downstream of the lake. Peak lake surface water (and discharge) temperatures are consistent with that anticipated during the consent process. However, the frequency that the moderate effects threshold for native stream fauna has been exceeded in the Te Awa O Katapaki Stream downstream has been less than anticipated. This is likely due in part to the mixing of the lake discharge with cooler flows from a large butt jointed stormwater main within the lakes outlet structure.

Elevated stream temperatures were expected to be mitigated within a 750 m long well shaded reach of stream downstream of the lake. The rate of cooling has been less than anticipated with an average reduction of 0.8 °C.

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REFERENCES

Aldridge B; Hicks B.J. 2006. The distribution of fish in the urban gully system streams of Hamilton City. CBER client report prepared for Environment Waikato and Hamilton City Council.

Auckland Council, (2013), Auckland Unitary Plan stormwater management provisions: Technical basis of contaminant and volume management requirements. Prepared by Auckland Council. Auckland Council technical report, TR2013/035.

Boswell J.; Russ M.; Simons M. 1985. Waikato small lakes: resource statement. Waikato Valley Authority.

Chung P.Y. 2007. Thermal Impacts of Stormwater Retention Ponds and Constructed Wetlands. Master's Thesis, University of Auckland Faculty of Engineering. Funded by Auckland Regional Council.

Collier K.J; Cooper A.B.; Davies-Colley R.J.; Rutherford J.C.; Smith C.M.; Williamson R.B. 1995. Managing Riparian Zones: A contribution to protecting New Zealand's rivers and streams.

Galli J. 1990. Thermal Impacts Associated with Urbanization and Stormwater Management Best Management Practices. Produced by the Metropolitan Washington Council of Governments for the Sediment and Stormwater Administration of the Maryland Department of the Environment.

Ham J.; Toran L.; Cruz J. 2006. Effect of upstream ponds on stream temperature. Environmental Geology, 50: 55–61.

Jones M.P.; Hunt W.F.; 2010. Effect of Storm-Water Wetlands and Wet Ponds on Runoff Temperature in Trout Sensitive Waters. Journal of Irrigation and Drainage Engineering, 136(9): 656–661.

Kieser M.S. 2004. Stormwater Thermal Enrichment in Urban Watersheds (WERF Report 00-WSM-7UR). London: IWA Publishing.

Maxted J.R.; McCreedy C.H.; Scarsbrook M. R. 2005. Effects of small ponds on stream water quality and macroinvertebrate communities. *New Zealand Journal of Marine and Freshwater Research, Vol. 39*: 1069–1084.

Miller D.C.; Ralph, G.; Cochrane, P.R. 2013a. Hamilton City Council Comprehensive Stormwater Discharge Consent 105279: 2012/13 Monitoring Report. Consultancy report prepared for Hamilton City Council.

Miller D.C.; Law, D.; Cochrane, P.R. 2013b. Magellan Lake 2013 Environmental Monitoring Report. Consultancy report prepared for CDL Land (NZ) Ltd.

Olsen D.A.; Tremblay L.; Clapcott J.; Holmes R. 2012. Water Temperature Criteria for Native Aquatic Biota. Prepared for Auckland Council, Environment Waikato and Hawkes Bay Regional Council. Auckland Council Technical Report 2012/036.

Tonkin & Taylor 2005. Proposed Magellan Lake Ecological Assessment. Report prepared for CDL Land NZ Ltd, February 2005.

Tonkin & Taylor 2007. Proposed Magellan Lake Executive Summary Report. Report prepared for CDL Land NZ Ltd, October 2007.

Young D.; Afoa E.; Meijer K.; Wagenhoff A.; Utech C. 2013. Temperature as a contaminant in streams in the Auckland region, stormwater issues and management options. Prepared by Morphum Environmental Ltd for Auckland Council. Auckland Council technical report, TR2013/044