State of the Environment

Temperature Effects in Reservoir Creek

August 2007

This report presents results of an investigation of the continuous water temperature in Reservoir Creek over three summers from 2004-05 to 2006-07. Significant increases in stream temperature were found in unshaded parts of the waterway and due to a decorative in-stream pond. Implications for other parts of the region are provided.

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Executive Summary

High stream water temperatures are well known to reduce the life-supporting capacity of the waterway. Reservoir Creek, like many streams in the hottest driest parts of Tasman District is vulnerable to high water temperatures, particularly in unshaded reaches that experience the highest sunshine hours. The results of semi-continuous logging of temperature in Reservoir Creek over three summers have shown that from December to March water temperatures are regularly well above established thresholds for our native fish and invertebrates. The reach between Hill Street and Templemore Dr is where most of the heating is occurring (average 6^{o}C increase), followed by Templemore Ponds (1.5^{o}C increase) where water is particularly slow-moving and open to heating from the sun. It is recommended to isolate the parts of the reach that are contributing most of the heating and undertake targeted riparian planting to create shade.

Generally streamside planting to create shade over waterways should be encouraged in the sunniest parts of the district particularly Waimea, Moutere, Motueka and parts of Golden Bay. Additionally care needs to be taken in designing any in-line (in-stream) ponds to ensure that heating is not an issue.

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1.0 Introduction:

The aim of deploying temperature loggers at six sites along the length of Reservoir Creek was to answer the following questions:

1. What is the background water temperature as the stream comes out of a fully shaded system?
2. What is the effect of a relatively open section of low gradient waterway (Hill St to Templemore Drive)?
3. What is the effect of rock rip-rap on water temperatures?
4. What is the effect of Templemore Ponds? In-line ponds are well known to cause large thermal increases for several hundred metres downstream (eg Maxted et al 2004).
5. What is the rate of recovery of stream temperature after a section of shading?

This report covers temperature monitoring in Reservoir Creek over three summers (2004-05, 2005-06 and 2006-07). After the 2005-06 summer, it was decided that we needed to confirm the pattern of temperature and to narrow down the main area contributing to temperature elevation between the Marlborough Crescent and Templemore Drive sites.

In-line ponds, such as the Templemore Ponds, are well known to cause significant increases in water temperature, often for hundreds of meters downstream (Maxted et al 2004).

When temperatures rise, the capacity of the water to retain dissolved oxygen reduces. The effects of high temperatures and low dissolved oxygen on stream ecology is well known. See Figure 1 for thresholds of daily maxima and daily minima for water temperature and dissolved oxygen (respectively).

The water temperature statistic “midpoint of daily max and daily mean” has been found to be the most important temperature determinant for fish survival. National Institute of Water and Atmosphere has undertaken research that shows water temperatures over 21.5^{o}C cause 50% of the mayflies and stoneflies to die (LT_{50}). This threshold should be applied to temperatures midway between the daily average and daily maxima with diurnally varying data (Cox & Rutherford, 2000). The main drivers for high water temperatures in streams are: low humidity, high solar radiation (use LENZ & ~100 solar radiation monitoring stations in NZ) and low wind speed.

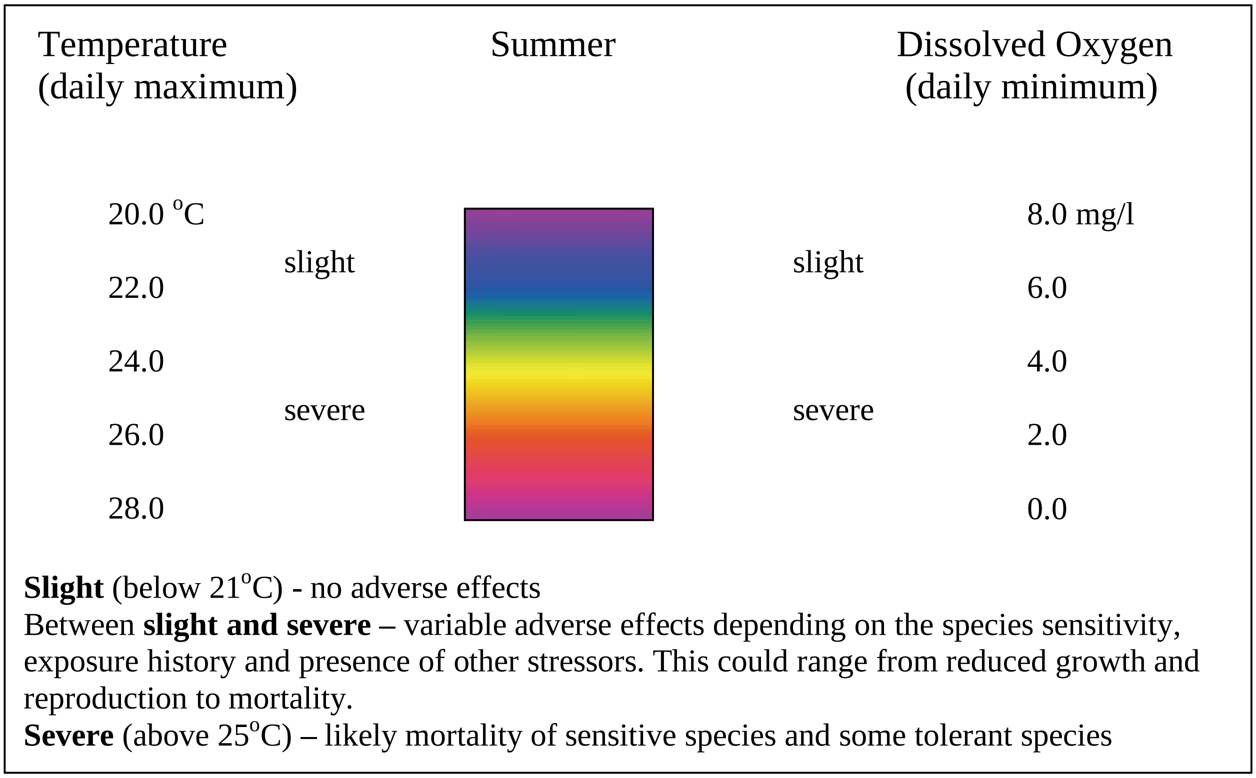


Figure 1: The effects of high water temperature and lower dissolved oxygen (taken from published literature).

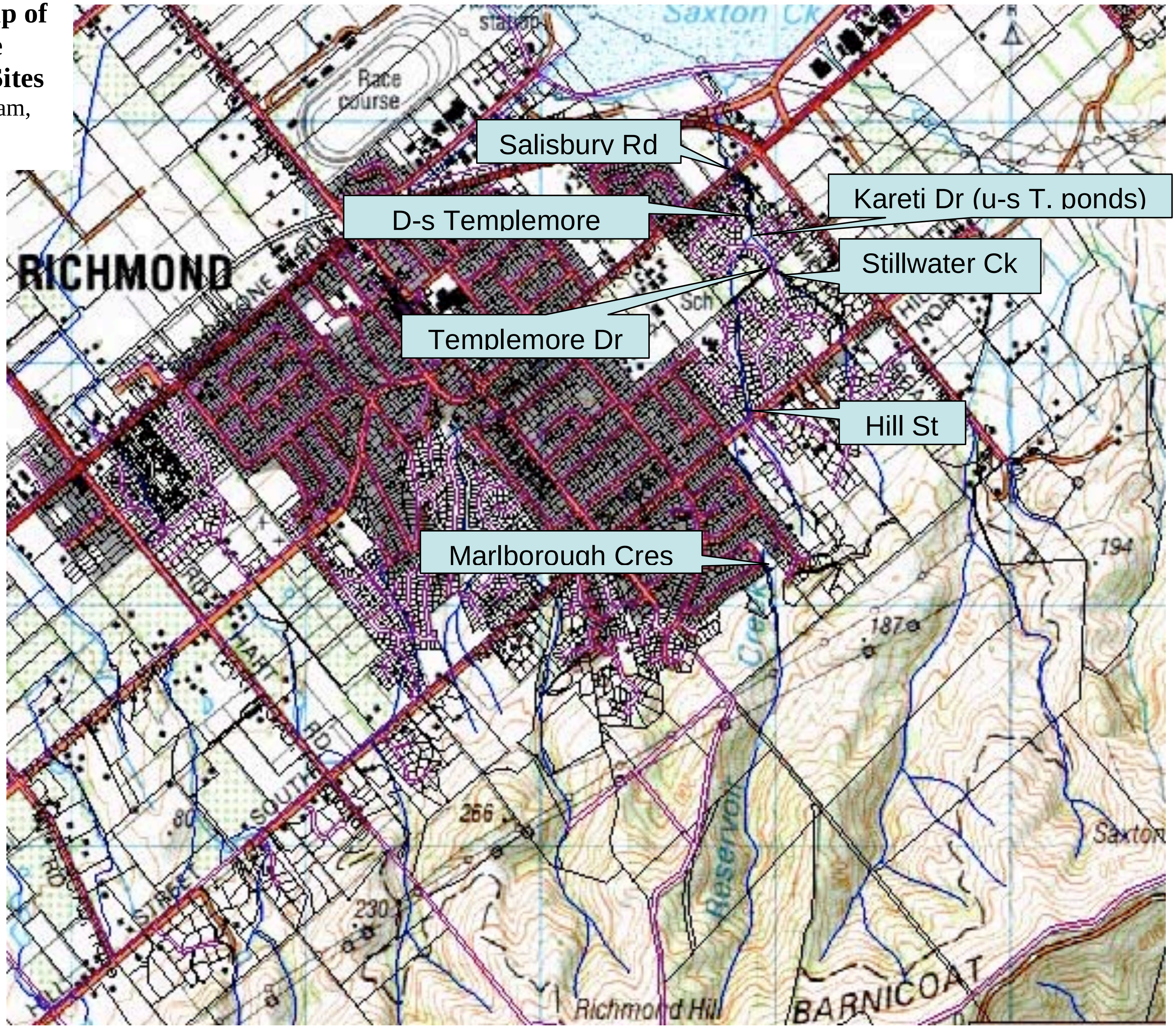
While some waterway monitoring has been undertaken in the Motueka catchment (Young et al. 2005), there is very little baseline data to compare the effects of in-line ponds and streamside vegetation in this region.

2.0 Methods:

StowAway® TidBit® loggers were used at all sites. Calibration was achieved by reference to a dry bulb thermometer prior to deployment. All sites we set to record at 30 minute intervals (except 2005-06 where 15 minute intervals were used).

Figure 2: Photograph of a logger similar to that used on Reservoir Creek (the coin is equivalent to a 10 cent piece)

Figure 3: Map of Temperature Monitoring Sites
(d-s = downstream, u-s = upstream)



3.0 Results:

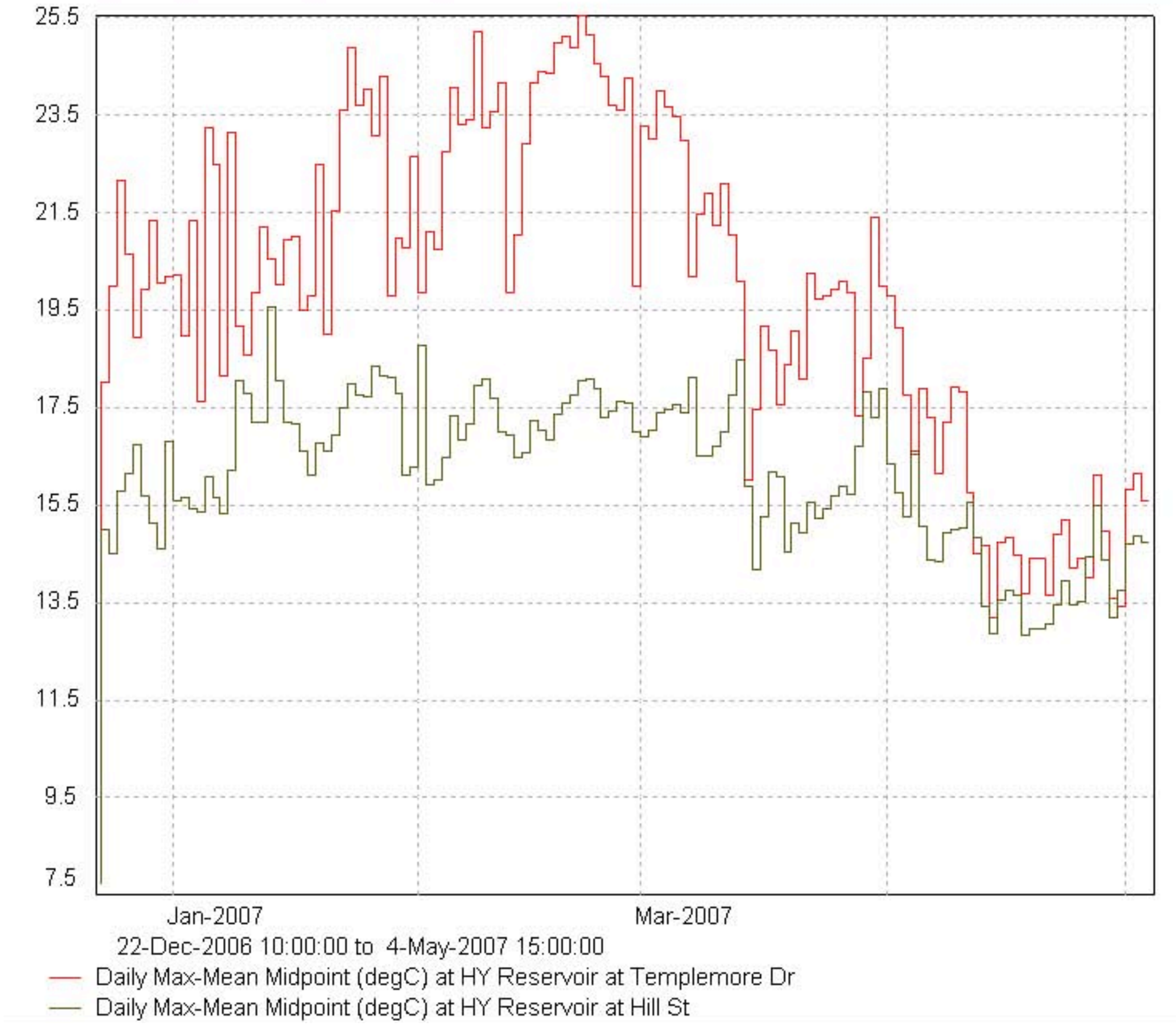
Table 1: Temperature statistics for Reservoir Creek (all temperatures in ^{o}C)

SITE	MAX TEMP		PERIOD OF PEAK DAILY MEAN TEMPS		MIDPOINT OF DAILY MAX & DAILY MEAN	
	2005-06	2006-07	2005-06	2006-07	2005-06	2006-07
Reservoir Ck at Marlborough Crescent	19.7	20.7	Mid Dec & Early Feb	21-28 Jan	19	19.5
Reservoir Ck at Hill Street	-	21	-	Jan-Early Mar	-	19.4
Reservoir Ck 10m upstream Templemore Drive	27.9	29	Mid Dec & Late Feb	Mid Jan to Early Mar	25	25.2
Stillwater Ck 10m upstream of Reservoir Ck	28.3	-	Late Feb		24	-
Reservoir Ck 20m upstream Kareti Drive	27.3	27	Early Feb	Mid Jan to Early Mar	23	24
Reservoir Ck 10m downstream of Templemore Ponds	28.9	26.7	Early Feb	Mid Jan to Early Mar	27.5	24.4
Reservoir Ck 30m downstream Salisbury Road	25.7	-	Early Feb	-	24.5	-

The results (Table 1) show:

1. At the most affected sites there were 60-80 days where maximum temperatures were above 21.5^{o}C
2. In both years there was a large increase in water temperature (maximum and mean) after passing through 685m of largely soft-bottomed, low gradient bed that is relatively poorly shaded (Hill Street to Templemore Drive). Figure 3a and b clearly show the difference between the two sites in the 2006-07 summer. The average increase in temperature between the sites from mid January 2007 to early March 2007 was 6^{o}C.
3. There was a significant increase in the midpoint of daily max and daily mean temperatures due to Templemore ponds (see Figure 4a-c). The average increase over the ten highest temperature days was 1.3^{o}C in 2005-06 and 1.5^{o}C in 2006-07. The greatest increase was 4.5^{o}C in the 2005-06 summer. The temperature range between daily maximum and daily minimum is lower downstream of the ponds (average 5^{0}C) compared to 7-8^{o}C for the stream inflow to the ponds indicating a thermal buffering of the water by the pond.
4. Both years showed a slight decrease in stream temperature from Templemore Dr to Kareti Dr (apart from 6 Feb where there was a 1^{o}C increase when the temperature of Stillwater Creek was over 1^{o}C lower than Templemore Dr). The thermal reservoir effect of rip-rap may be mitigated by the fact that stream gradient increases over this section resulting in greater turbulence and cooling.
5. There is a significant recovery of stream temperature (average of 3^{o}C reduction in the midpoint of daily max and daily mean on the highest water temperature days) between Templemore ponds and Salisbury Road (approximately 330m) this is likely due to both shading and some turbulent flows (no data for 2006-07).

Figure 4a: Overplot of the midpoint of daily mean and daily maximum water temperature for Hill St (green) and Templemore Dr (red) sites



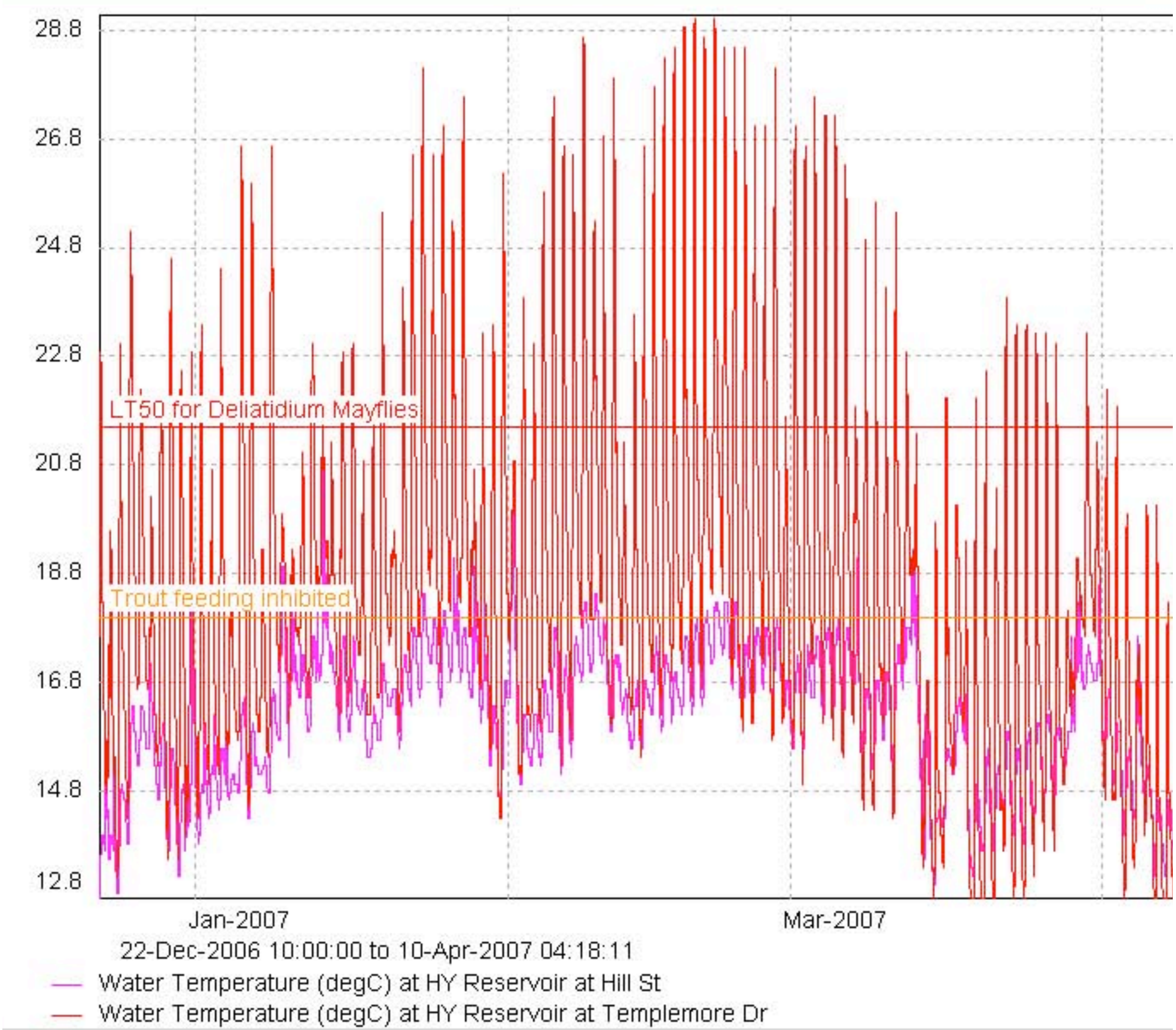


Figure 4b: Overplot of the absolute water temperature from Hill St (pink) & Templemore Dr (red) sites

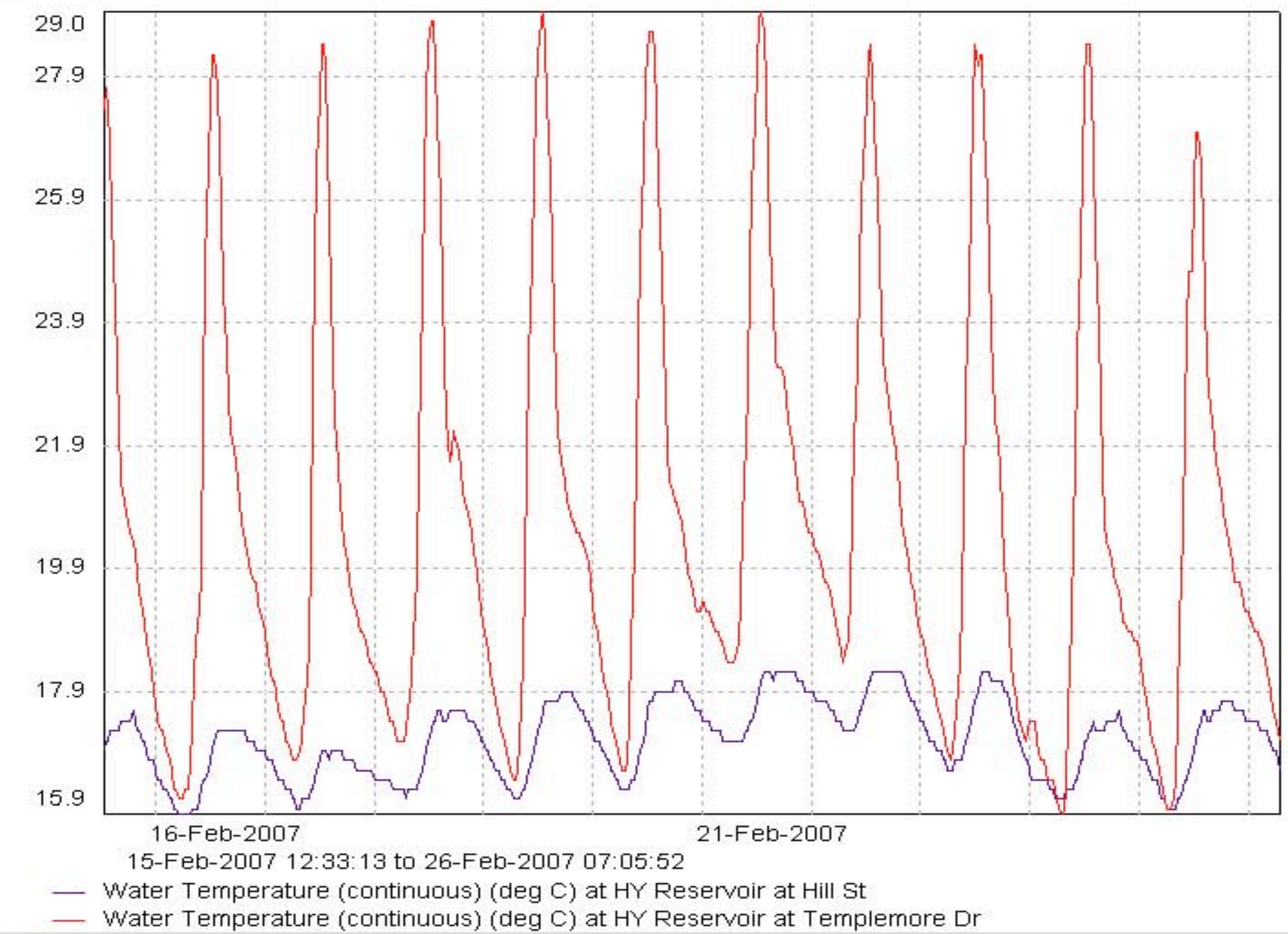
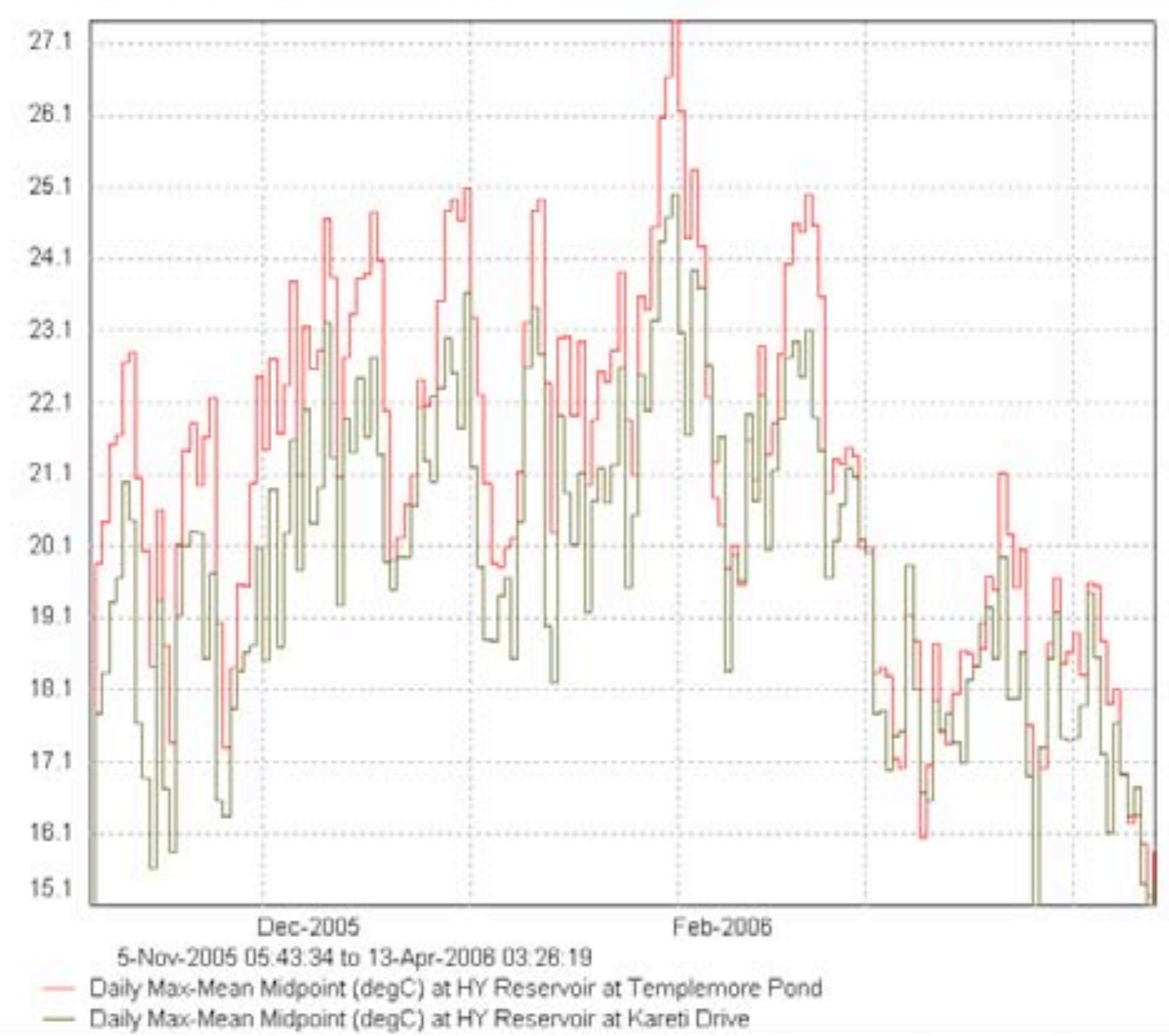


Figure 4c: Overplot of water temperature from Hill St (pink) and Templemore Dr (red) sites 16-26 February, 2007 (zoom in from Figure 3a).

Figure 5a: Overplot of the midpoint between the daily mean and daily maximum water temperature from Kareti Dr (pink) and downstream Templemore Pond (red) sites (2007).



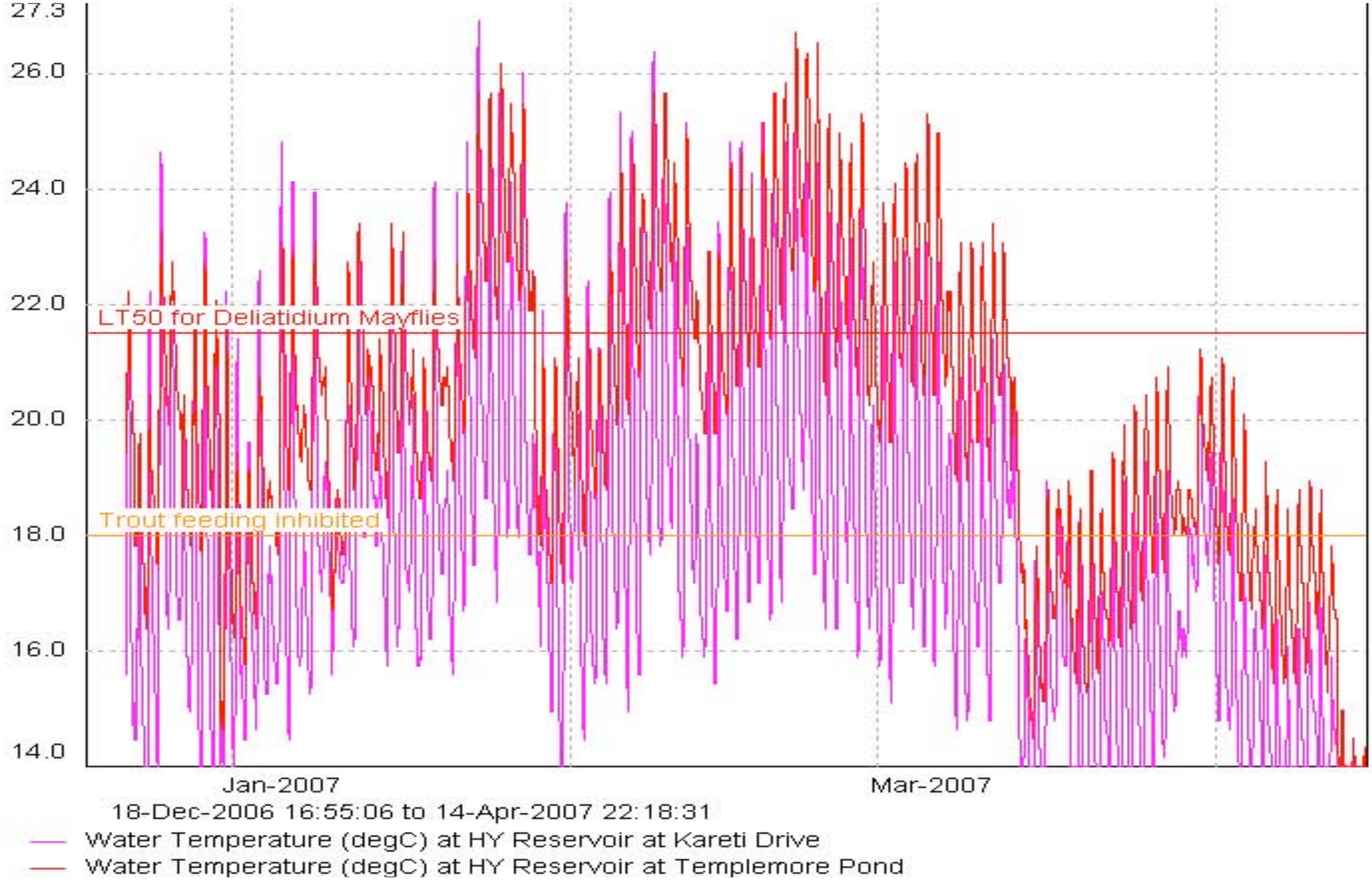


Figure 5b: Overplot of absolute water temperature from Kareti Dr (pink) and downstream Templemore Pond (red) sites (2007).

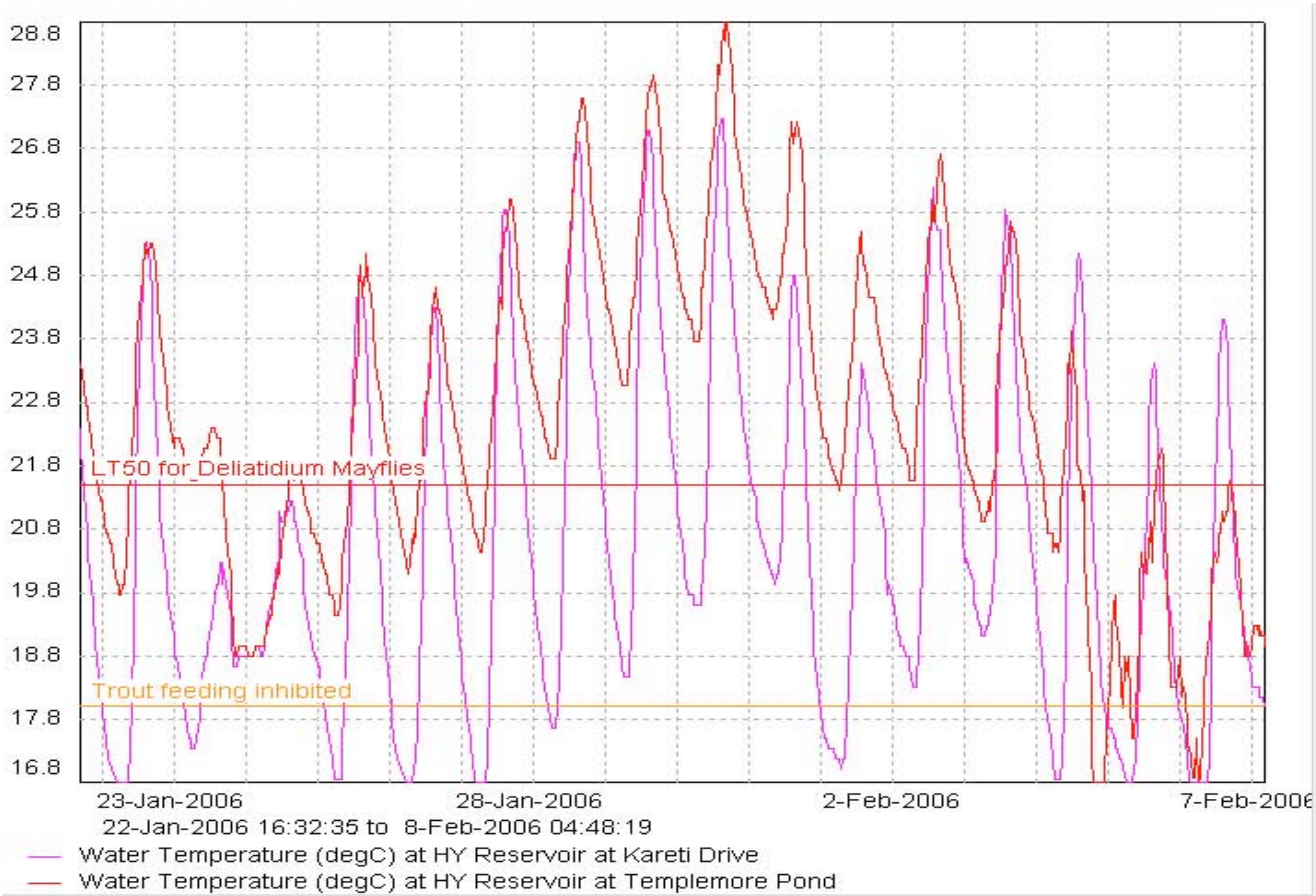


Figure 5c: Overplot of water temperature from Kareti Dr (pink) and downstream Templemore Pond (red) sites 21 Jan - 10 Feb 2006 ((Zoom in on Figure 5b).

4.0 Discussion:

4.1 Reservoir Creek

The peak daily mean temperatures occurred in February 2007 which is similar to the previous summer, however instead of a gradual rise from November, the Dec 2005 temperatures were a lot higher at most sites due to unusually low rainfall over the spring.

The 2006-07 summer results confirm that the highest priority for shading of Reservoir Creek is in the section between Hill Street and Templemore Drive. It is possible that there is a warm discharge, such as stormwater, somewhere in this reach which may be exasibating the temperature increase. It is recognized that stream works are required for approximately 100m upstream of Templemore Drive to increase flood flow capacity according to engineering estimates and it will not be possible to do any planting in this area until such time as an additional strip of land is purchased to enable widening the creek. This will have implications for the recovery of fauna in the creek.

Downstream of the Templemore Ponds the daily mean was considerably higher than for the Kareti Dr site (due to the daily minimums being higher). Lower variability in diurnal water temperature downstream of the Templemore Ponds is due to thermal buffering which is typical for large water bodies as the inertia to heat and cool is much greater. In addition atmospheric temperatures have less influence because the ponds surface area to volume ratio is much lower.

There was surprisingly little variation in temperature patterns over the summers monitored, particularly with respect to the influence of Templemore ponds (see Appendix Three).

Diversity and abundance of invertebrates in Reservoir Creek is much lower than expected at Tasman District Council's 'State of the Environment' monitoring site at Salisbury Road compared to the Marlborough Crescent (upstream) site. Macro-invertebrate Community Index values are typically 70-90 at Salisbury Rd and 100-120 at Marlborough Crescent. Although there are elevated nutrient (particularly nitrogen) and disease-causing organism concentrations, these are not at levels that, on their own, could cause such an adverse effect on the invertebrate population.

4.2 Stream Temperature Issues Across the Region

Stream temperature is likely to be a widespread issue in Tasman, particularly in smaller, unshaded waterways in the sunniest parts of the region. This includes Waimea, Moutere, Motueka and parts of Golden Bay. Spot measurements at many sites in the 'State of the Environment' Surface Water Quality Monitoring Programme as well as semi-continuous data from many sites have provided good evidence that high water temperatures are a significant issue throughout much of the region. These sites include the Motupiko (& tribs such as Kikiwa Creek), Sherry River, Little Sydney Creek, Waiwhero River and Lower Motueka River (Young et al. 2005) and Powell Creek in the Motupipi River Catchment in Golden Bay (James, T, 2007 unpublished). Invertebrate metrics at many of these sites indicate lowered life-supporting capacity of streams affected by high temperatures.

Modelling of stream temperature across the Tasman District indicates little change in shade from historic to contemporary conditions for small streams in catchments that remain in indigenous forest, but in small streams that have lost their riparian cover, the estimated temperature may be up to 5 degrees higher than under historic conditions (Leathwick, Unpublished data 2005; Davies-Colley et al 1998 & unpublished; Theurer et al 1984). This model estimated water temperature in small forested streams in January to be close to, or slightly below, the January air temperature. While these estimates are based on a very well-founded physical model, they should be used only as a broad indication of likely changes in water temperature (see Appendix Two for the main model inputs and assumptions). We would expect them to be most reliable for small streams having consistent levels of shade, i.e., where there has been ample opportunity for the stream to reach an equilibrium condition. Therefore the model is very reliable in lowland streams of low gradient in agricultural landscapes.

The model will be unreliable in streams descending steeply from high elevation, particularly where there has been a dramatic change in riparian cover immediately upstream. However, these streams are not at such high risk of temperature increase. Modelled predictions will be very unreliable where there are significant inputs from groundwater or caves. With these factors in mind, these model outputs should only be used as a broad indication or likely regional patterns, and that stream temperature data be collected to confirm this model.

The model seemed to predict the January mean temperatures very well. January mean present-day stream temperatures in lower Reservoir Creek were predicted by the model to be 20-21 ^{o}C, with mean temperatures found in this study being 20.5^{o}C (see Appendix 4.1 and 4.2). There was a similar good fit for the upper sites. The model predicted for Reservoir Creek increases in stream temperature above historic levels of 2-2.5^{o}C in the upper reaches (upstream Marlborough Crescent) in forestry land use and 3-3.5^{o}C in the lower reaches (downstream of Stillwater Creek) in urban land use. It would be useful if the model output could show the mid-point between the daily mean and daily maxima.

The Tadmor and Sherry Rivers, which the model predicts to have mean January temperatures of 21-24 ^{o}C would be an obvious priority for further investigation.

4.3 Improving Stream Temperature

Planting stream-sides not only produces shade and controls water temperature but has many other benefits including providing food (leaves & insect rain), improved habitat for fish and invertebrates and filtering of contaminants from runoff from the adjacent land. Aquatic habitat is improved particularly by the presence of roots and woody debris that provide cover for fish and erosion then creates a variety of depth zones.

Tasman District Council’s fencing fund helps rural landowners in the process of removing stock access from streams but does not provide plants for achieving good shade. A Sustainable Management Fund project involving the whole Reservoir Creek catchment has developed a management plan that addresses stream temperature, amongst other issues. Further streamside planting will be carried out by Tasman District Council’s Parks and Reserves Department.

5.0 Recommendations:

1. Further monitoring:
    a. Using hand-held temperature recorder, conduct a longitudinal temperature transect survey of Reservoir Creek from Hill St to Templemore Drive in the peak summer season (Jan-Feb) to determine the cause of increasing temperatures through this reach.
    b. Repeat the deployment of loggers at all Reservoir Creek sites in the summer of 2011-12 to see in the riparian planting has improved the situation.
    c. When resources permit survey other waterways in the sunniest parts of the district, particularly Waimea, Moutere, Motueka and parts of Golden Bay. It should be sufficient to install a logger at a site for only one summer, unless there is an unusually cool summer. Deployments will start in Sherry and Tadmor catchments.

2. Improving water temperatures:
    a. Streamside planting to create shade over the water should be encouraged in the sunniest parts of the district, particularly Waimea, Moutere, Motueka (in particular the Tadmor, Sherry, Dove, and Orinoco Rivers) and parts of Golden Bay in conjunction with other riparian enhancement programmes.
    b. Care needs to be taken in designing any in-line (in-stream) ponds to ensure that heating is not an issue.

6.0 References:

Cox TJ, JC Rutherford, 2000. Thermal Tolerances of two stream invertebrates exposed to diurnally-varying temperature. NZ J Marine & Freshwater Research Vol 34:203-208

Davies-Colley, R. J., Quinn, J. M. 1998. Stream lighting in five regions of North Island, New Zealand: control by channel size and riparian vegetation. *New Zealand Journal of Marine and Freshwater Research 32*: 591-605.

Davies-Colley, R. J. Rutherford, J. C. (unpublished) Some approaches for measuring and modelling riparian shade.

Leathwick, J, 2005 (unpublished). Model of Stream Temperature for Tasman District.

Maxted, J. R.; McCready, C. H.; Scarsbrook, M. R.; Spigel, R. H. 2004. Effects of small ponds on water quality and macroinvertebrate communities in Auckland streams, New Zealand. *New Zealand Journal of Marine and Freshwater Research.*

Rutherford JC, Davies-Colley RJ, Quinn JM, Stroud, MJ, Cooper AB, December 1999. Streams Shade: Towards a Restoration Strategy. National Institute of Water and Atmosphere & Department of Conservation.

Theurer, F.D., K.A.Voos, and W.J.Miller. 1984. Instream water temperature model. Instream Flow Information Paper 16 (peer reviewed). US Fish and Wildlife Service. FWS/OBS-84/15. 300 pp.

Young, R.; James, TI; and Hay, J: 2005 State of Surface Water Quality in Tasman District.

Appendix One: Data Editing

Records were complete and reliable up until the flood on Anzac Day (25 April, 2006). This flood caused two sites to be inundated with silt by over 100mm (Stillwater Ck 10m upstream of Reservoir Ck & Reservoir Ck 10m upstream Templemore Dr) and the site downstream of Templemore Ponds to get washed out (logger found washed up beside the creek).

Appendix Two: Notes on Modelled Estimation of Water Temperatures

Stream temperature modeling carried out by John Leathwick as part of the Department of Conservation-funded Freshwater Environments of NZ project in 2005 used the following methods and inputs:

1. Equilibrium water temperatures were estimated for all REC reaches for January and July using the equilibrium water temperature model of Theurer et al. (1984).

2. All climatic input variables were derived from 100 m resolution rasters provided by Landcare Research as follows:

    - Average monthly air temperature (°C);
    - Average 9 am humidity (%);
    - Average soil temperature at 30 cm depth (°C);
    - Average daily solar radiation ($MJ/m^2/day$);
    - Average sunshine hours (proportion of maximum possible);
    - Average daily wind speed (km/hr).

3. Shade was estimated for each reach based on its flow (m^3/sec) and estimated vegetation height (m) as follows.

    - The wetted channel width was computed using the relationship width = 7.8289 * (MeanFlow ** 0.4777), taken from unpublished data provided by Ian Jowett;
    - Total river bed width was estimated as wetted width /0.75, based on data published in Davies-Colley & Quinn 1998;
    - For current shade, the riparian vegetation in a surrounding 100 m buffer was identified from the Land Cover Database. Where more than one type of vegetation occurred along a river segment, the shading was estimated for each, and then the average was computed for the entire segment;

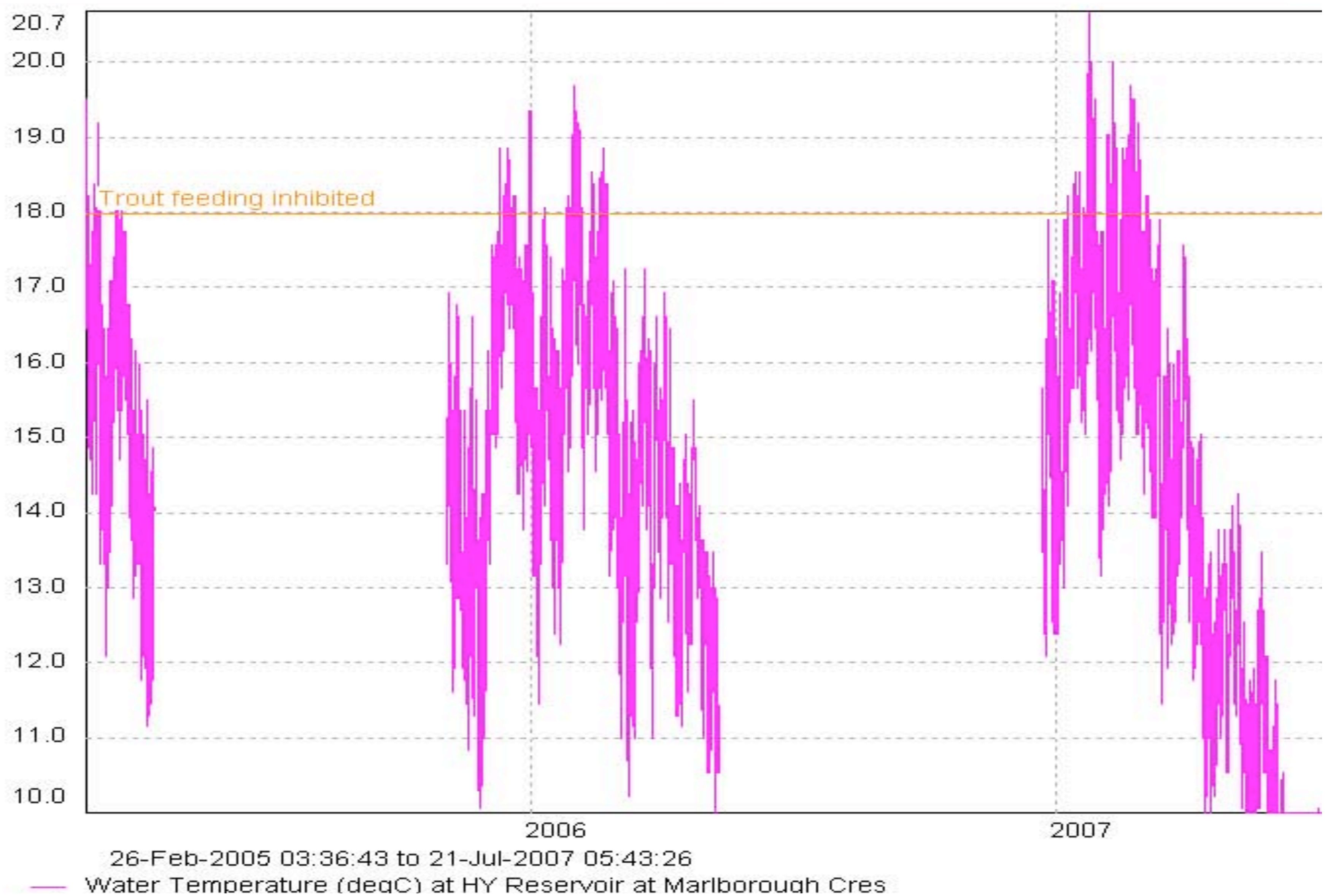
- For the historic shade, the potential vegetation cover was determined by overlaying the coordinates of the central part of the segment onto a raster layer describing New Zealand's potential vegetation (Landcare Research unpubl). Coastal dune and wetland vegetation were allocated a canopy height of 2 m, while scrub below treeline (dry areas below treeline, mostly in central Otago) was allocated a vegetation height of 8 m. Canopy height for all other vegetation (i.e. forest and scrub and tussock grassland above treeline) was estimated from the January air temperature using the relationship canopyHeight = (-0.1635 * JanTemp**2) + (7.2987 * JanTemp) - 47.96, based on a regression fitted to vegetation profile data collated by Wardle (1991). Temperature estimates were derived for each vegetation profile by interrogating the January average air temperature used in 2 above. Canopy height ranges from approximately 30 m on warm northern, lowland sites, 10 m at approximately 11 °C (treeline), and reach a value of 0 at about 8 °C, i.e., the approximate upper limit of vegetation;

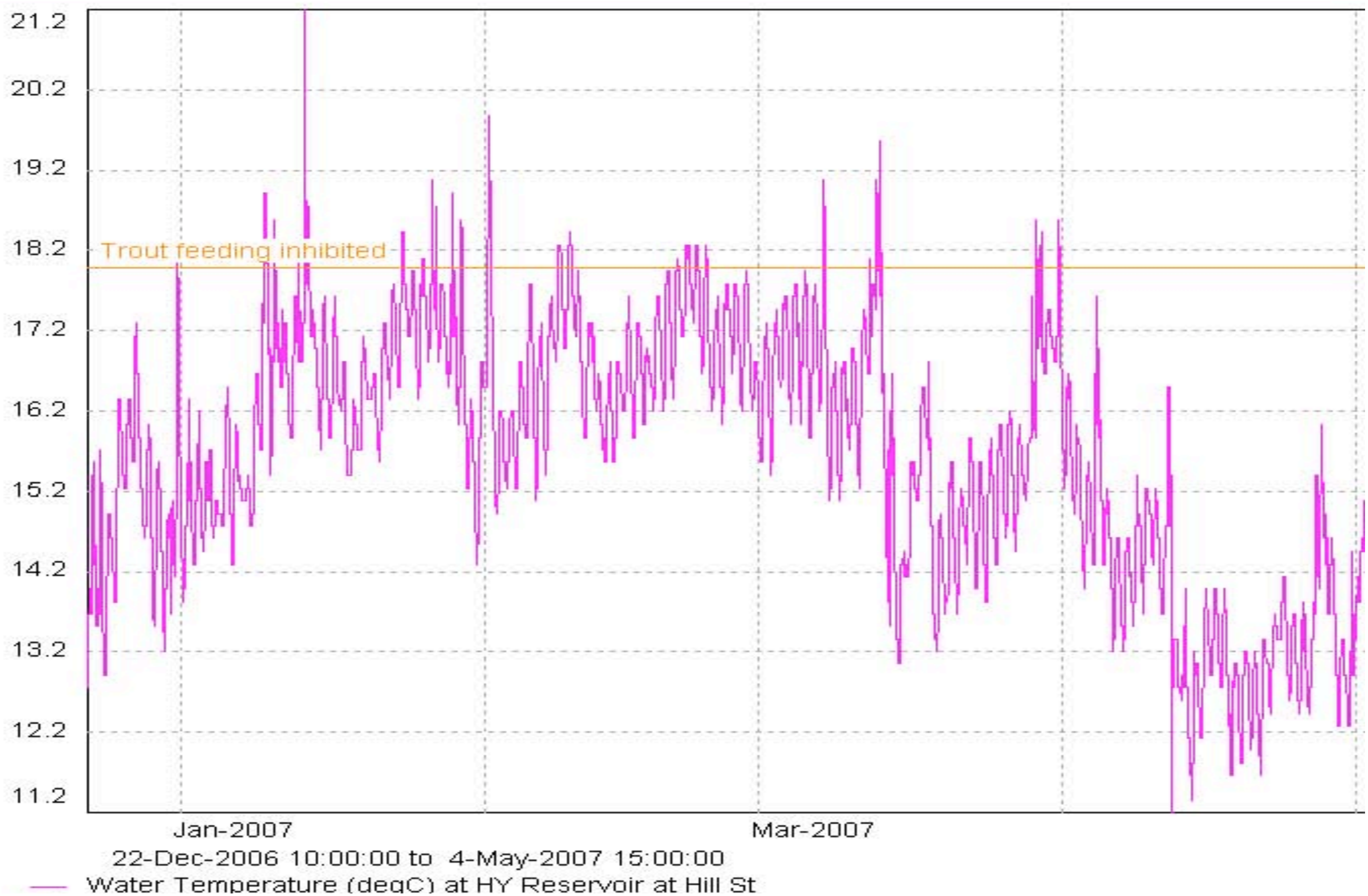
- Shading under diffuse light conditions was estimated as $\cos(\text{canopyAngle})^2$, where the canopy angle is the angle from the river centre line to the top of the adjacent canopy. Forest was assumed to have a density of 80% so that shading values range from 0 (unshaded) to 0.8 in heavily shaded reaches (Davies-Colley & Rutherford unpubl);

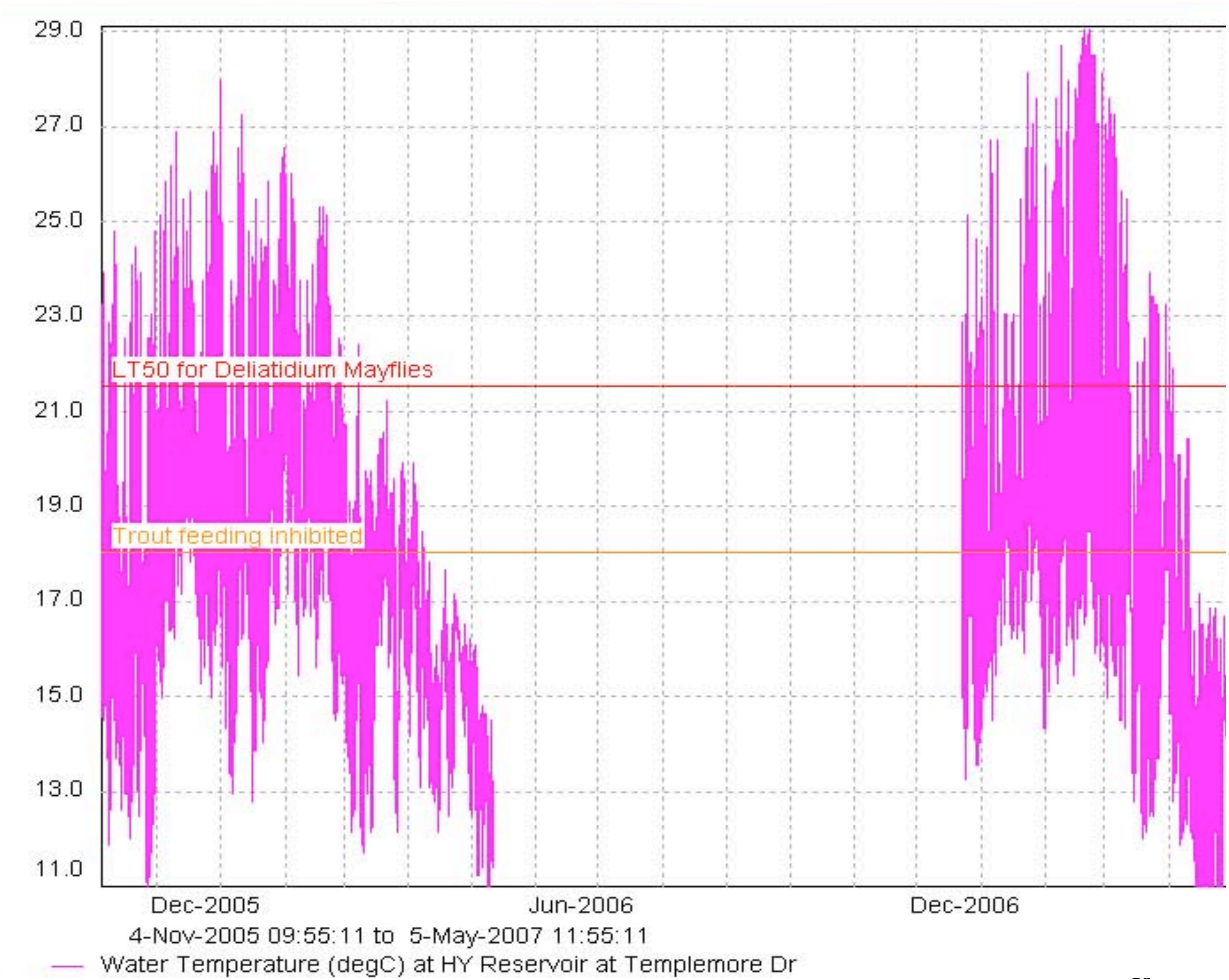
4. Water temperature values were initially estimated for reaches at their down-stream end, but for many coastal reaches, end-points fell beyond the extent of the underlying climate layers. Estimates were therefore recomputed using the coordinates of each reach mid-point. For a small number of sites (<100 in each island) this still resulted in the coordinates intersecting null regions of the climate layers, and these were re-run using coordinates for the upper end of the reach.

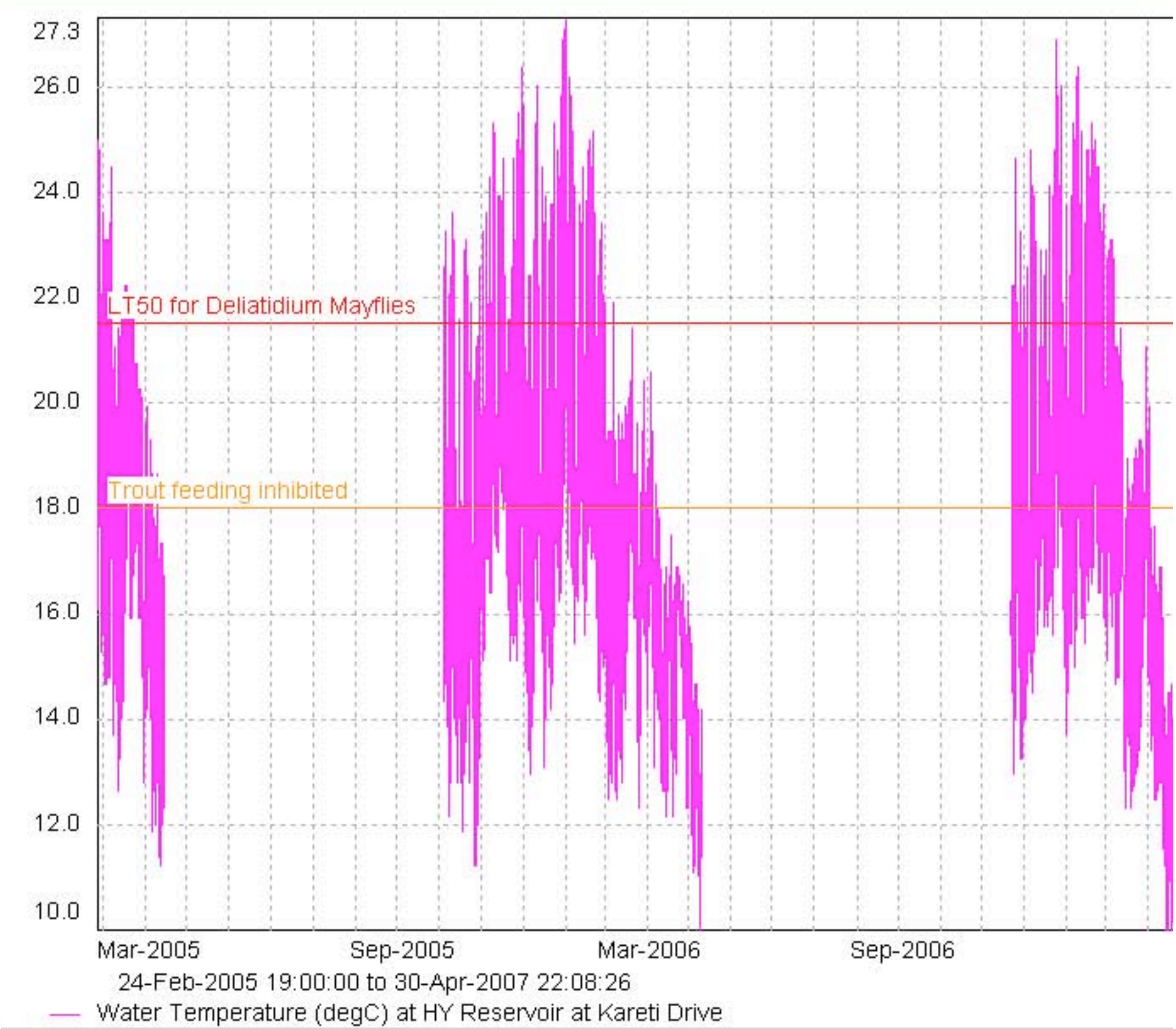
5. Validation – it appears that there are no readily available seasonal averages for sites in the water quality network (WQN), and it would take some time to port the data from Excel into Access and compute summaries. Visual inspection of predicted temperatures against the raw WQN data suggests that Theurer's model tends to work well for many sites, particularly where lowland rivers run over extensive alluvial plains, but over-estimates temperatures for high-volume, steep gradient rivers. This is most severe for some West Coast rivers, e.g., the Haast, where the model predicts an equilibrium summer temperature of 22 degrees, while the warmest measurements from this site from the WQN are around 13 degrees.

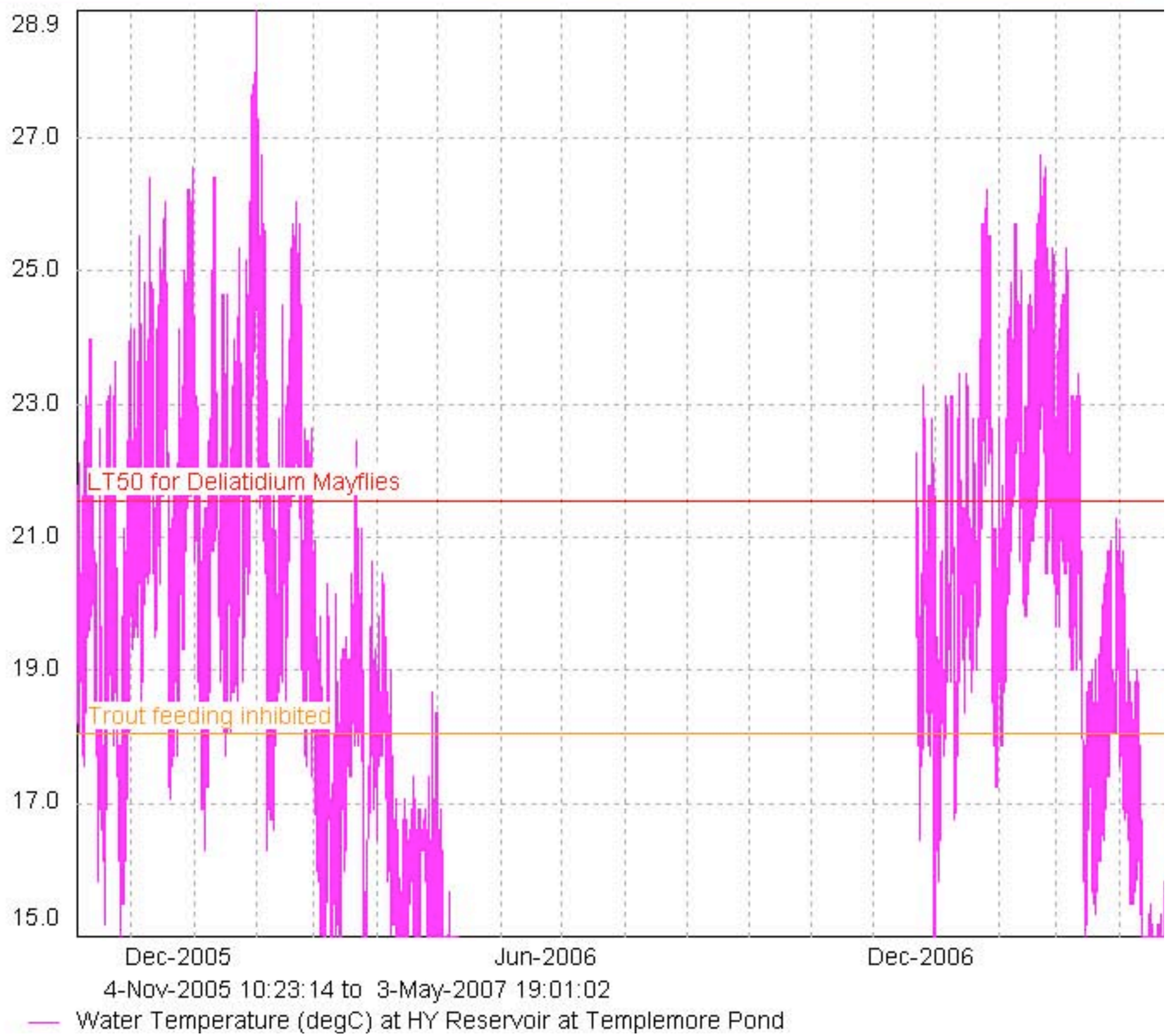
Appendix Three: Temperature data for the Reservoir Creek sites

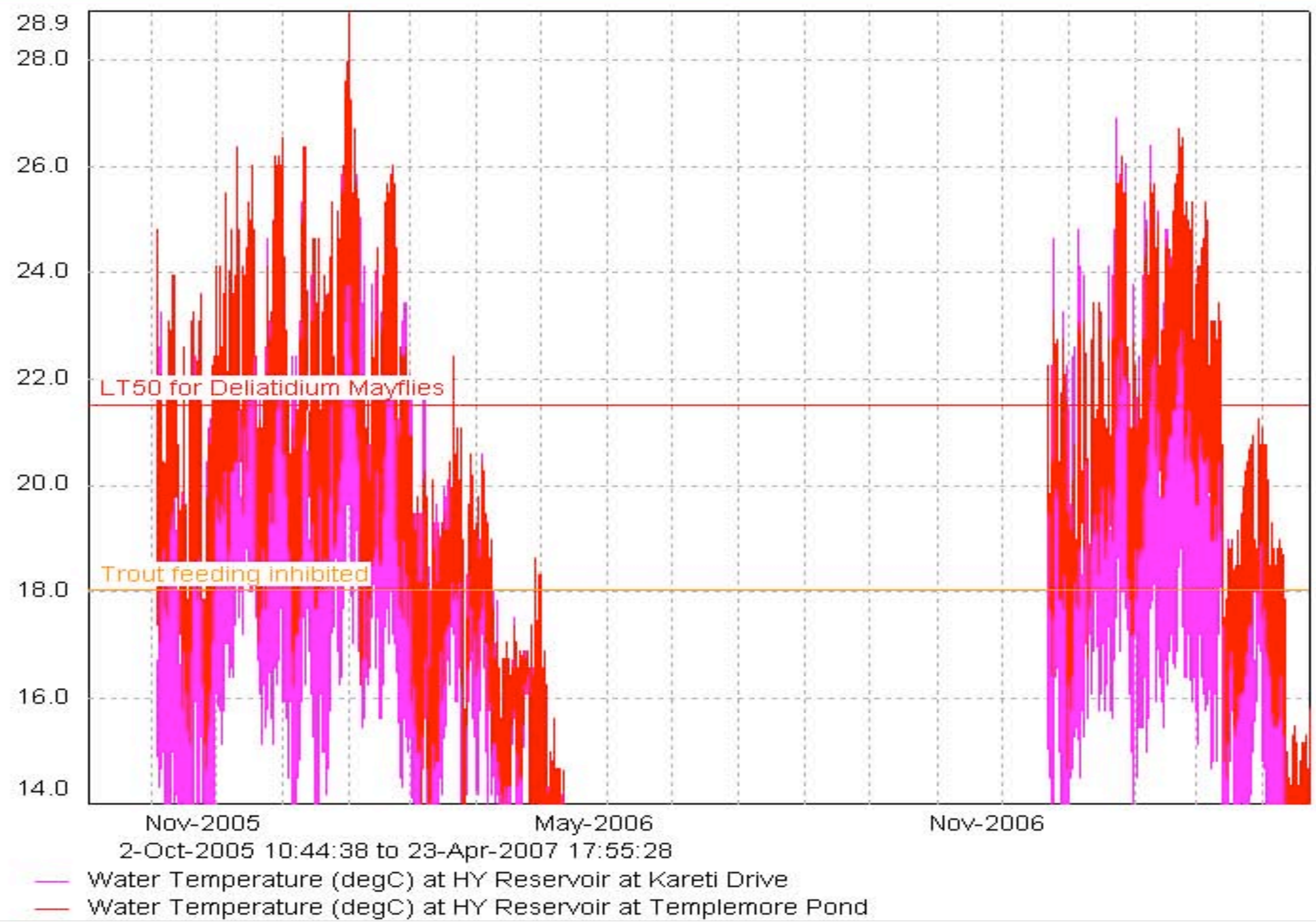



21.2
20.2
19.2
18.2
17.2
16.2
15.2
14.2
13.2
12.2
11.2
Trout feeding inhibited
Jan-2007
Mar-2007
22-Dec-2006 10:00:00 to 4-May-2007 15:00:00
Water Temperature (degC) at HY Reservoir at Hill St

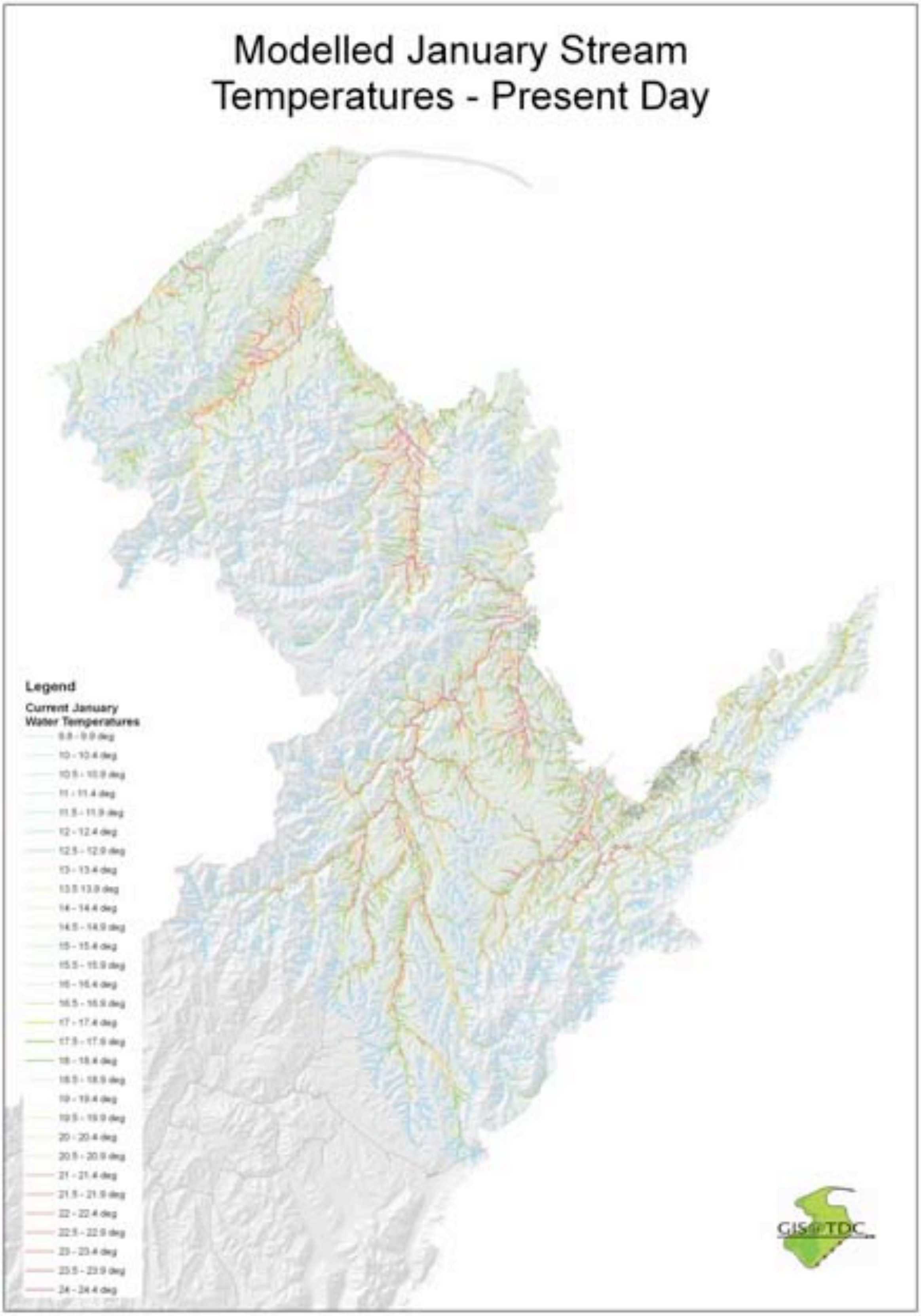

29.0
27.0
25.0
23.0
21.0
19.0
17.0
15.0
13.0
11.0
LT50 for Deliatidium Mayflies
Trout feeding inhibited
Dec-2005
Jun-2006
Dec-2006
4-Nov-2005 09:55:11 to 5-May-2007 11:55:11
Water Temperature (degC) at HY Reservoir at Templemore Dr


27.3
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
LT50 for Deliatidium Mayflies
Trout feeding inhibited
Mar-2005
Sep-2005
Mar-2006
Sep-2006
24-Feb-2005 19:00:00 to 30-Apr-2007 22:08:26
Water Temperature (degC) at HY Reservoir at Kareti Drive


28.9
27.0
25.0
23.0
21.0
19.0
17.0
15.0
LT50 for Deliatidium Mayflies
Trout feeding inhibited
Dec-2005
Jun-2006
Dec-2006
4-Nov-2005 10:23:14 to 3-May-2007 19:01:02
Water Temperature (degC) at HY Reservoir at Templemore Pond


28.9
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
LT50 for Deliatidium Mayflies
Trout feeding inhibited
Nov-2005
May-2006
Nov-2006
2-Oct-2005 10:44:38 to 23-Apr-2007 17:55:28
Water Temperature (degC) at HY Reservoir at Kareti Drive
Water Temperature (degC) at HY Reservoir at Templemore Pond

Appendix 4.1 – Modelled Present-Day Stream (Average January) Temperature for Tasman District (Note that the model ignores the influence of cooling groundwater. This influence will be significant in waterways such as Riwaka, Pearse and Baton Rivers)



Appendix 4.2 – Modelled Difference Between Present-Day and Historic Stream (Average January) Temperature for Tasman District (Note that the model ignores the influence of cooling groundwater. This influence will be significant in waterways such as Riwaka, Pearse and Baton Rivers).