Appendix 8

Wekepeke Temperature Survey

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Wekepeke Temperature Analysis
Introduction

The composition of aquatic fauna in rivers may be highly dependent on the water temperature. Water temperature regulates a number of physiological and chemical processes that shape the structure of native communities (Brett, 1971, Elliot, 1981, Wehrly *et al.*, 2003). Water withdrawals may modify thermal conditions by reduction of instream flows, hence increased solar penetration, by intercepting groundwater intrusions or by impoundment related thermal anomalies (Ballesterro *et al*., 2006, Lessard and Hayes, 2003, Maxter *et al.*, 2005, Parasiewicz *et al.*, 2007, Walden and Parasiewicz, 2005).

Impoundments can cause an increase in river temperatures because the pooled water is heated by solar energy. The resulting warmer river temperatures can lead to a disruption in available local fauna habitat by decreasing dissolved oxygen and creating strain on the species fitness. As a result, the more tolerant generalist species (frequently non-native) that thrive in the warmer water may out-compete the native coldwater fauna.

On the other hand, large reservoirs can have the opposite effect by lowering water temperatures through cold-water bottom releases as well as eliminating diurnal fluctuations. Large impoundments are usually thermally stratified with the coldest layer, or hypolimnion, on the bottom during the summer. This phenomenon has been documented to be responsible for severe damages to the native fish fauna in places such as the Colorado River downstream of the Glen Canyon Dam (Clarkson & Childs, 2000). Currently, all of the dams within the Wekepeke study area are managed as "run of the river"; meaning surface water is entering the river by spilling over the dam.

The Northeast is home to coldwater species such as Atlantic salmon, brook trout and slimy sculpin that are not able to tolerate sustained temperatures in excess of 25°C (Wehrly *et al*., 2007). Each species may have water temperature requirements for different life stages. Temperature can trigger life history events such as spawning or hatch time, which may also modify the fauna composition (e.g. delayed hatch of fish larvae could shorten the growth season and increase winter mortalities of juvenile fish). For coldwater species, the increase of summer temperatures above lethal thresholds is a key regulator of population fitness; therefore, at this stage we focused our efforts on investigating summer thermal patterns to determine if the survival conditions for coldwater fish are still maintained in the upper Wekepeke Brook.

Wekepeke Temperature Data

Loggers in the Wekepeke Brook watershed study area were installed strategically to provide insight as to the effect of water withdrawals on native fauna. The loggers were distributed along the Wekepeke Brook and two important tributaries, Lynde and Spring Brook.

Five Onset HOBO® water level loggers and nine temperature pendant loggers were installed by Rushing Rivers Institute (RRI) in the Wekepeke watershed for the period between June 20, 2008 and November 18, 2008. Temperature was recorded at 15-minute intervals throughout the duration of the study period. Eight of the fourteen loggers were installed in the mainstem of the Wekepeke, four in the Spring Basin area, and two in the Lynde Basin (**Figure 1**). One of the loggers located at the upstream end of Spring Basin was incorporated into a beaver dam and was not recovered.

We will proceed by analyzing the period common to all loggers covering 152 days. This record covers most of the Salmon Spawning and GRAF (generic resident adult fish) Spawning bio-period, and the entire Rearing and Growth bio-period. The recorded time series on each logger were analyzed and are presented further in this report.

Table 1: Logger distances downstream from the Heywood Reservoir (Wekepeke) or upstream from the confluence with Wekepeke Brook (Lynde and Spring Basin) and daily minimum, average, and maximum temperature values (°C).

ID	Location	Distance(m)	Min	Avg.	Max
TL01	Wekepeke Brook	65	8.2	19.8	26.2
WL06	Wekepeke Brook	886	6.7	16.2	21.8
WL34	Wekepeke Brook	1683	4.9	16.1	23.1
TL07	Wekepeke Brook	2025	4.9	16.2	22.9
TL08	Wekepeke Brook	3197	4.2	15.9	23.2
TL09	Wekepeke Brook	3456	5.2	15.4	21.8
TL10	Wekepeke Brook	3895	4.3	15.3	21.8
WL05	Wekepeke Brook	4444	4.6	15.7	22.5
TL04	Spring Basin	754	7.0	9.7	11.3
TL05	Spring Basin	507	6.0	19.1	27.0
TL06	Spring Basin	464	5.2	17.8	25.1
WL09	Spring Basin	278	9.6	14.6	17.7
TL02	Lynde Basin	304	7.2	12.4	15.4
WL07	Lynde Basin	285	6.6	16.8	23.2

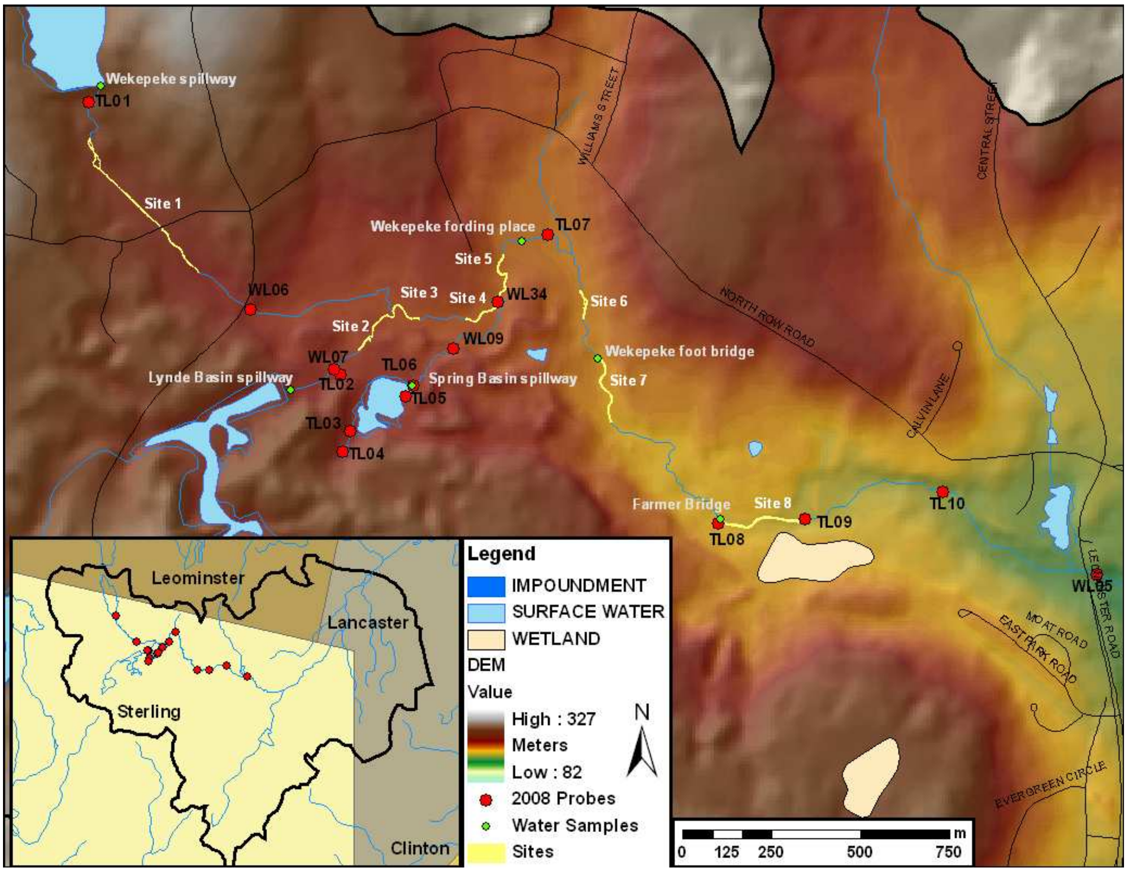

Figure 1: Map of the temperature-recording loggers placed in the Wekepeke study area during the 2008 study season.

Results

Wekepeke Brook

The loggers installed on the Wekepeke Brook follow a similar pattern throughout the study period. Located near the outlet of the Heywood Reservoir, TL01 remains at a consistently higher temperature than the other loggers on the Wekepeke mainstem. This parallel deviation from the other loggers continues until the end of October, when temperatures begin to converge with the other seven loggers (**Figure 2**). There is temperature fluctuation throughout the study period, and the temperatures follow expected seasonal trends. Temperatures peak in July and generally decrease throughout the remainder of the study period.

The maximum temperature recorded in the Wekepeke Brook of 26.2°C occurred at logger TL01, on August 1. This record is 3°C warmer than the next warmest temperature of 23.2°C recorded at logger TL08, but is lower than the overall study area high of 27°C recorded at logger TL05 in the Spring Basin (**Table 1**).

Average temperatures for all loggers on the Wekepeke main stem, except TL01, start at approximately 16°C at the beginning of the study period and they peak on July 9. The temperature fluctuates throughout the study period, staying mainly between 15°C and 21°C before steadily decreasing at the end of the growing season, starting in mid-September.

Although temperatures steadily decrease overall, there are periods of rapid temperature drops and increases (i.e. from October 16-24 and October 24-26), which are likely due to precipitation events and local temperature fluctuations.

The minimum temperature of 4.2°C on the Wekepeke main stem was recorded on November 18, at logger TL08. This was 4°C cooler than the lowest temperature recorded at logger TL01, located in close proximity to the outlet of Heywood Reservoir. It is also the lowest temperature recorded at any logger during the study period.

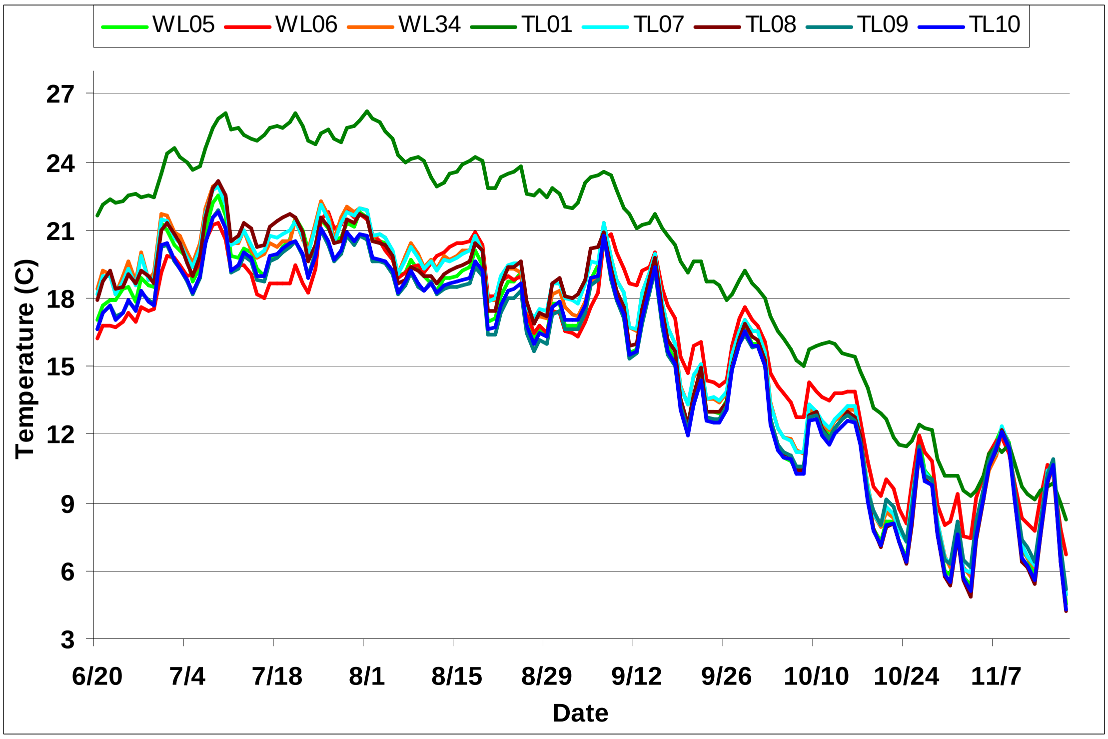

Figure 2: Average daily temperatures for all loggers located on the Wekepeke Brook for the period of June 20 to November 18.

The longitudinal variability of the measured temperatures for the Wekepeke Brook is shown in **Figure 3**. The uppermost logger in our study area, logger TL01, exhibits the highest minimum, average, and maximum temperatures. Temperature decreases significantly downstream between TL01 and WL06 and then remains steady over the remainder of the logger locations. There is a slight variation in minimum and maximum temperatures throughout the study area. These values tend to oscillate between logger sites, but downstream loggers exhibit less temperature range, with slightly higher low temperatures and slightly cooler high temperatures than their upstream counterparts.

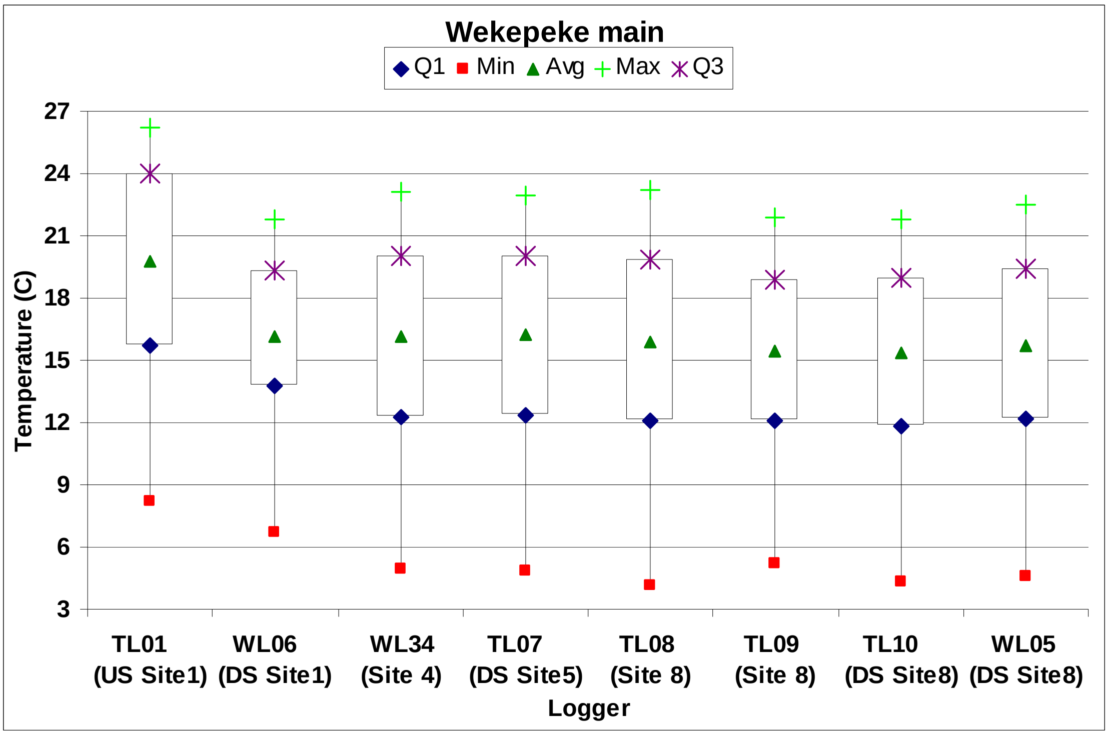

Figure 3: Longitudinal profile of the loggers on the Wekepeke Brook starting from those closest to the Heywood Reservoir, then moving downstream. Measurements are averaged for the study period and include minimum, average, maximum and quartiles 1 and 3.

Spring Basin

At the time of installation, the Spring Basin loggers' temperatures varied from approximately 9° C - 22° C. Logger TL04 was installed at the surface source of Spring Brook and records the spring water temperature at the head of a small pond above Spring Basin. The temperature at this logger is steady throughout the study period and shows less influence of seasonal and weather related variability. The temperatures at loggers TL05 and TL06 fluctuate more or less in tandem during this period. TL05 was installed near the downstream end of Spring Basin approximately 20m from shore. TL06 was installed immediately downstream of the pipe which serves as the outlet of Spring Basin. Temperatures recorded at TL06 were typically slightly cooler than the surface waters of Spring Basin. WL09, like TL04, also records a relatively stable range of temperatures throughout the study period. The instrument was installed in a stilling well downstream of Spring Basin and likely records a mixture of surface and groundwater temperatures.

The maximum temperature for these loggers (27°C) was observed at TL05 on July 10, and again on July 19. This was the highest temperature recorded at any logger location during our study period.

The daily average temperature throughout this study period for logger TL04 remains between 9° C and 12° C until the beginning of October when the temperature starts to decline. Logger WL09 remains between 14° C and 18° C until the end of September, after which it cools steadily through the remainder of the record. Loggers TL05 and TL06 display a temperature pattern influenced by atmospheric and meteoric variations similar to the record shown above for the main stem Wekepeke. The minimum temperature recorded at the Spring Basin complex is 5.2°C at logger TL06 on the day of recovery.

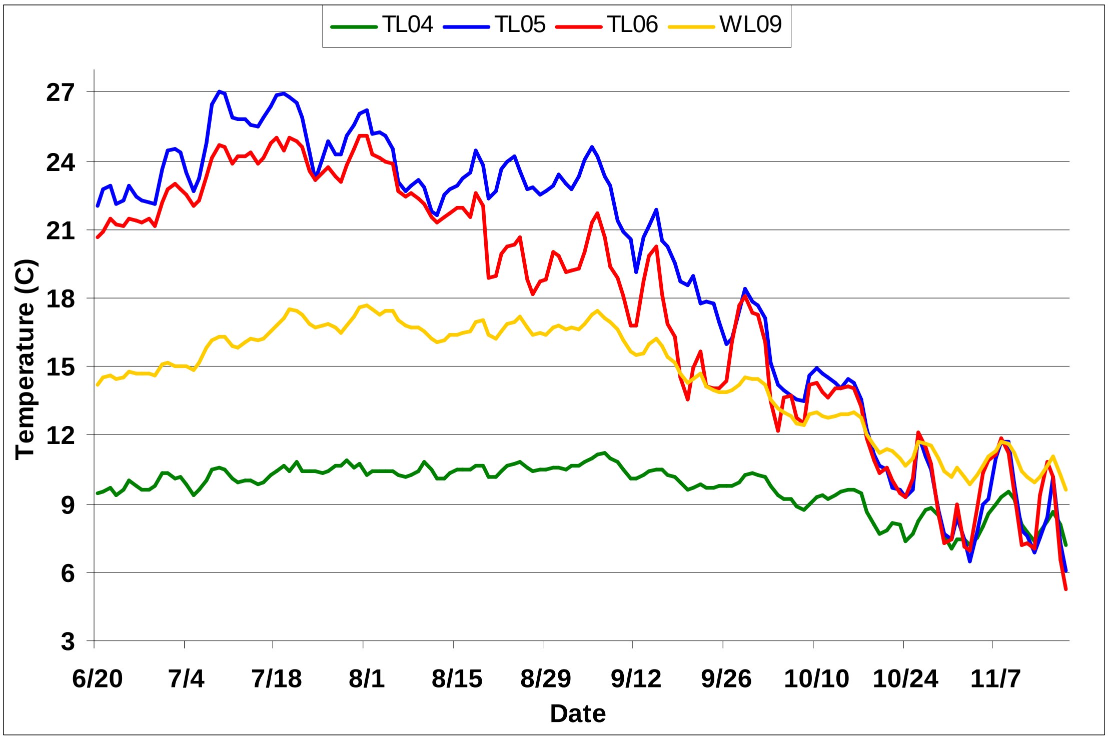

Figure 4: Average daily temperatures for all loggers located in the Spring Basin for the period of June 20 to November 18.

Figure 5 demonstrates the longitudinal variability of the measured temperatures with the help of descriptive statistics. Logger TL04 is located at the headwater of Spring Brook and has the lowest average and maximum temperatures. The average daily temperature increases at the next logger downstream then decreases at the next two loggers. The minimum temperature decreases from logger TL04 to TL06, then increases at WL09. The maximum temperature increases from TL04 to TL05, then decreases at the next two loggers.

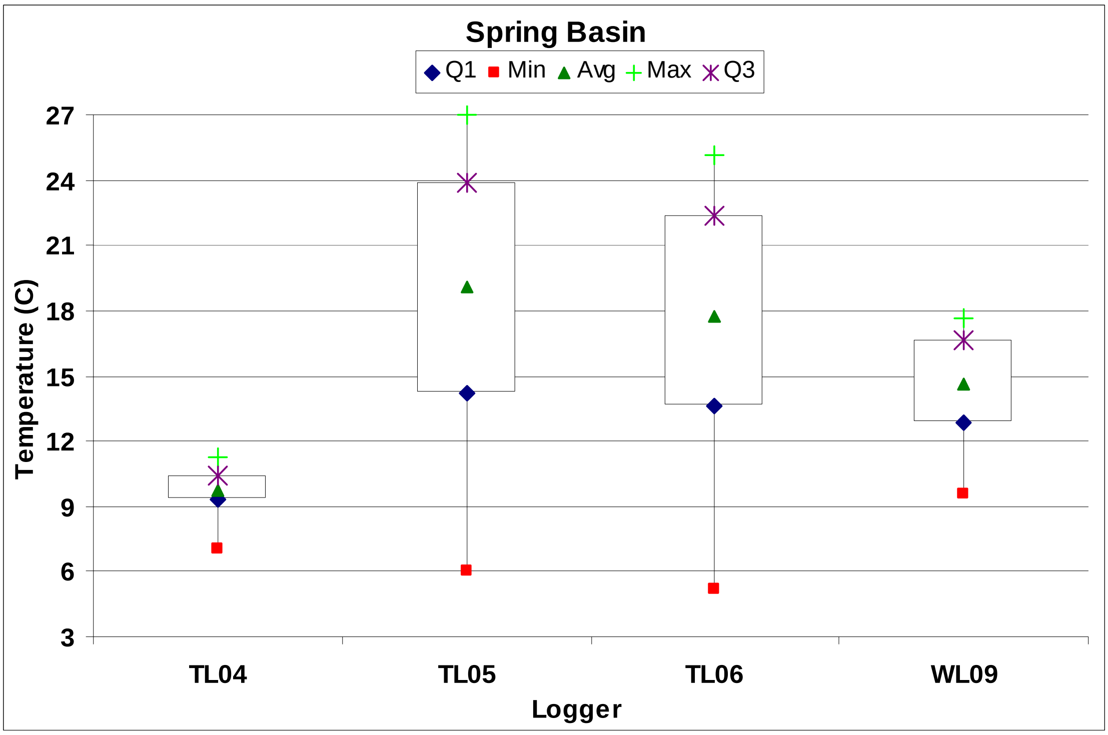

Figure 5: Longitudinal profile of the loggers on the Spring Basin, starting from the Spring and then moving downstream. Measurements are averaged for the study period and include minimum, average, maximum and quartiles 1 and 3.

Lynde Basin

The two Lynde Basin loggers record a 9°C difference in temperature between them at the time of installation. Though the loggers record vastly different temperature signatures, the signatures respond similarly to climatological events throughout the study period. TL02 was installed in a small tributary to Lynde Brook, which we consider to be the original channel before the construction of the riprapped spillway associated with Lynde basin. WL07 was installed approximately 5m upstream of where this small tributary enters Lynde Brook. The temperatures begin to converge near the end of the study period, reaching the same temperature on October 10 before tracking each other closely for the remainder of the study (**Figure 6**). Beginning at the end of October, logger TL02 maintains an equal or greater temperature than WL07 for the rest of the study period.

A maximum temperature of 23.2°C was recorded at logger WL07 on July 25 (**Figure 7**). The average temperature of logger TL02 varied between 11°C - 15°C and logger WL07 oscillates between 6°C and 24°C throughout the study period. The minimum temperature recorded in Lynde Basin was 6.6°C at logger WL07.

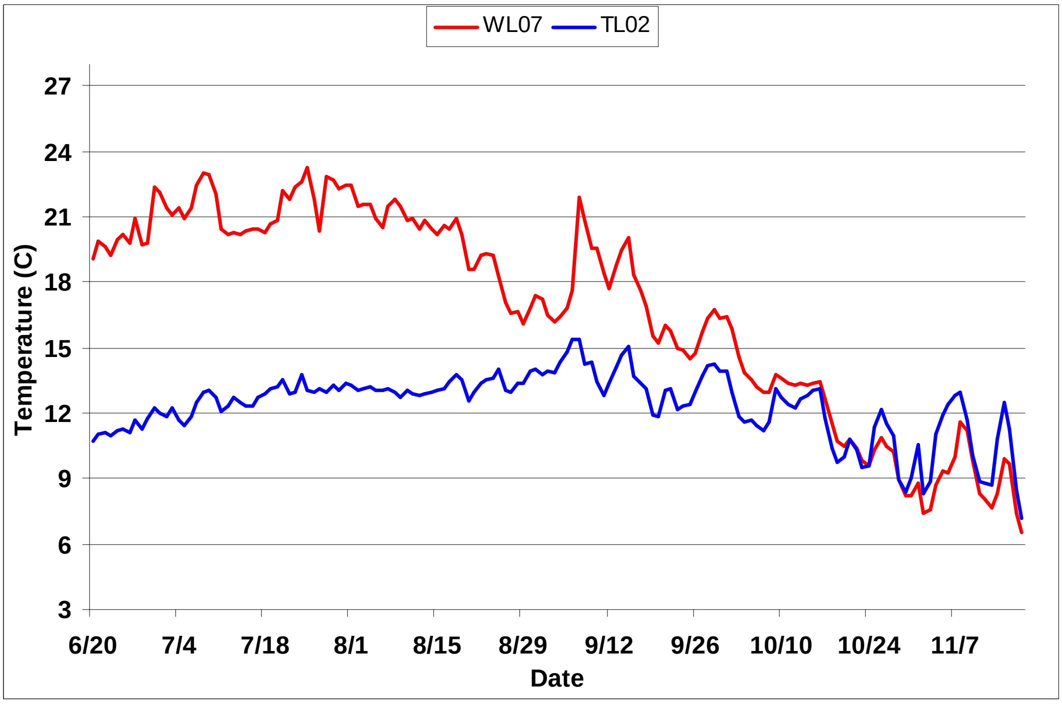

Figure 6 (above): Average daily temperatures for loggers located in the Lynde Basin for the period of June 20 – November 18.

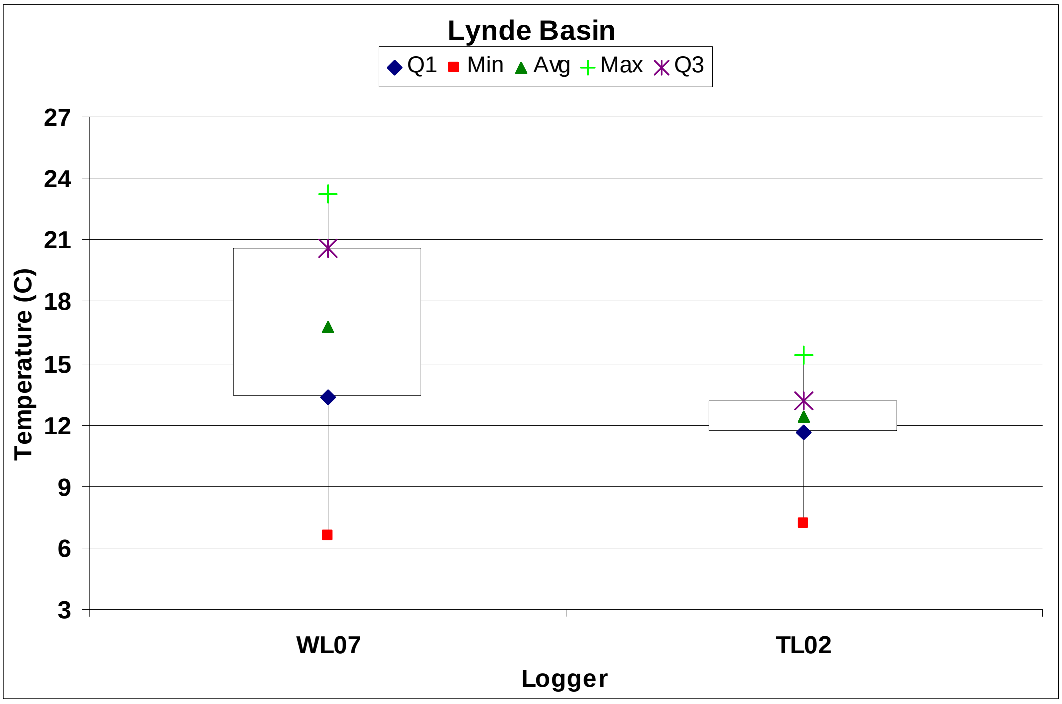

Figure 7: Average daily temperatures for loggers located on the Lynde Basin for the period of June 20 to November 18.

Discussion

Analysis of the thermal data indicates that groundwater contributions, as well as seasonal air temperatures, drive the river water temperatures in the Wekepeke system. River temperatures, in the summer months, stay between 15°C and 24°C, except for logger TL01, which stays between 21°C and 26°C. Overall, these conditions make the brook suitable for coldwater fisheries.

River temperatures typically increase downstream along a longitudinal profile, but in this instance, the furthest upstream logger TL01 records the warmest temperatures in the mainstem Wekepeke study area. This logger is heavily influenced by the surface water temperatures exiting the Heywood Reservoir, which originates from a spillover on the dam and from water flowing through a beaver deceiver drainpipe. The temperature at this location is therefore elevated from what would normally be expected of a headwater stream. The next logger downstream, located near Heywood Road, records a decrease in average temperature most likely due to increased contributions of groundwater. The average temperature then remains relatively stable at subsequent downstream loggers. This trend differs from other rivers that we have studied throughout the northeast. Typically, the warming effect of the headwater impoundment is observed, followed by a downstream cooling trend, and then eventually begins to warm further downstream. The sustained temperatures observed on the Wekepeke longitudinal temperature profile are likely related to the abundance of infiltrating groundwater. Although, the small size of the study area limits our ability to assess the downstream warming trend, it is possible that the brook will experience the same type of temperature trend of other similar systems further downstream.

Two temperature loggers were installed within the Lynde Brook basin. Logger WL07 was installed at the downstream end of the Riprapped canal associated with the Lynde Basin spillway. Several meters further downstream, a small tributary enters Lynde Brook; logger TL02 was installed approximately 20m upstream in this tributary. We believe that this tributary is the former Lynde Brook channel before the construction of the Lynde Basin and the engineered spillway channel. Despite being disconnected from the system by the canal’s construction, the former channel continues to carry flow, which is likely a combination of natural groundwater seeps and springs associated with the hydraulic head created by Lynde Basin. The temperatures recorded in this tributary are significantly cooler than those recorded in Lynde Brook. The majority of Lynde Brook’s discharge upstream of this location is derived from the basin’s spill over and a 1.5” diameter pipe, siphoning additional water from an undetermined depth within the basin. Judging by the consistent contribution of cool groundwater in the Lynde tributary it appears as though the Basin is significantly elevating the temperature above what would occur here naturally and is thus contributing to warming of the Wekepeke mainstem.

Spring Basin loggers depict a warming trend when viewed from TL04 to TL06. The temperature increases from the outlet of the spring to the basin’s downstream end. The impounded surface water counteracts the spring’s consistent low temperature by increasing water temperatures in stagnant areas that heat up quickly. A large area of groundwater at WL09 then brings the temperature back down before the Spring Brook joins with the Wekepeke.

The temperature patterns recorded by loggers installed within the Spring Basin complex were different from what was originally expected. The logger TL04 placed near the spring's source recorded a steady, cold groundwater outflow which was largely unaffected by seasonality and the study period's meteoric influences. The next logger installed downstream was unfortunately lost, but its proximity to the spring source would lead us to believe that it would have recorded temperatures similar to, if not slightly higher than, TL01. Logger TL05 was deployed near the downstream end of Spring Basin in the shallow, recently flooded forest fringe. This probe recorded the surface water conditions of the reservoir, which proved to be warmer than was expected considering the temperature of water entering the basin. Spring Brook begins downstream of this logger at the earthen dam where a pipe drains the basin. Logger TL06 was installed in the small pond associated with the basin drainage system. It appears as though the warmer surface waters siphoned from Spring Basin begin to mix with the cooler groundwater leaking through the earthen dam resulting in the slight cooling observed at this logger location. Further downstream, where Spring Brook becomes more established, we installed a water level logger (WL09) in a test well drilled into the channel. It is difficult to decipher whether this logger is recording surface water conditions, groundwater temperatures or, more likely, a combination of the two. The temperature at this location is significantly colder than the upstream logger and is much less influenced by environmental factors, leading us to believe that it is not reflecting surface water temperatures. Without a logger installed further downstream in this system, it is difficult to say what the temperature at the confluence with the Wekepeke may be. However, temperature records from loggers installed immediately upstream of the Spring Brook confluence and one located 340m downstream indicate that the Spring Brook surface water temperature may not have a significant influence on the temperature profile of the Wekepeke. After this initial investigation, it is clear that an alternative logger distribution plan would allow for a more in depth analysis of the temperature relationship between Wekepeke and Spring Brook.

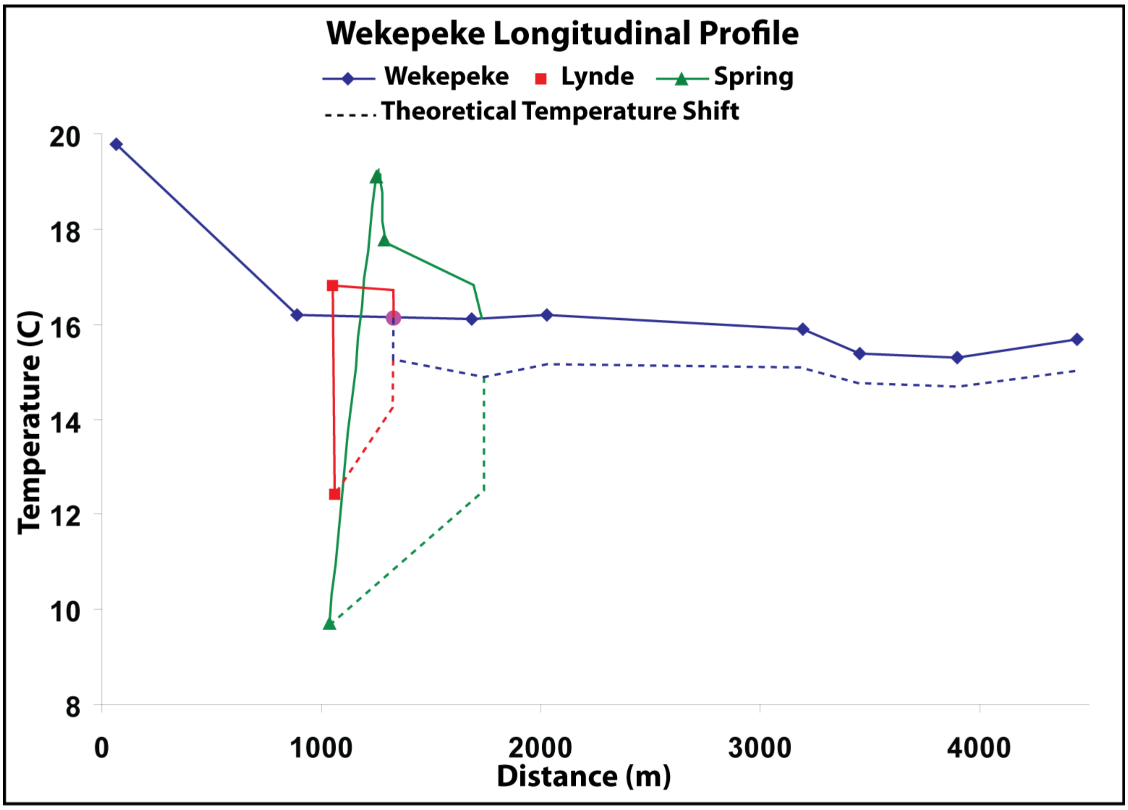

Figure 8: Conceptual diagram of Wekepeke Watershed temperature longitudinal profile. Solid lines represent average temperatures recorded during the 2008 study period and are plotted by logger location downstream of the Heywood Basin. Dashed lines are a theoretical temperature regime after dam removal or modification restoration scenario.

The study area of the Wekepeke watershed is a complicated network of man-made impoundment basins and their associated small tributaries. Water leaving all three of the main basins indicates the presence of elevated temperatures due to solar heating of the impoundments surface. The cooling trend at downstream loggers along with data from instruments installed in other tributaries supports a high degree of connectivity with base flow and groundwater intrusion. Loggers installed upstream of Spring Basin indicate the presence of a constant feed of cold spring water. This cold water is retained in the basin downstream thereby reducing its potential influence on mainstem Wekepeke temperatures. Despite the presence of these three impoundments and the associated records of thermal loading, the mainstem of the Wekepeke remained relatively cool suggesting that it is possible for the stream to support a cold-water fishery as hypothesized. Removal of some of the impoundment structures or re-engineering of their outlets may allow for additional flow and additional cool water to enter the system further improving the thermal structure of the study site.