# Walter Hardman Project Water Use Plan

# Walter Hardman Temperature Effects Monitoring

**Implementation Year 5**

**Reference: WHNMON-4**

**Lower Cranberry Creek Temperature Effects Monitoring**

**Study Period: 2007 – 2012**

**Final Report**

**K. Morrone Revelstoke,**
**B.C.**

And

**Triton Environmental Consultants Ltd.**

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## EXECUTIVE SUMMARY

The Walter Hardman hydroelectric project is located approximately 25 km south of Revelstoke, B.C. within the Monashee Mountain range. The Walter Hardman Dam is a run of the river operation on Cranberry Creek. Under the Walter Hardman Project Water Use Plan (2006), the Walter Hardman Water Use Planning Consultative Committee developed several programs designed to monitor outcomes of the recommended operational changes and changes to physical works at the generating facility. One of the proposed operational changes is to maintain an annual minimum discharge of 0.1 $m^3s^{-1}$ into Lower Cranberry Creek. An anticipated benefit of providing the minimum discharge is improvement of fish habitat, through lower summer water temperatures, and continuous winter flows (i.e. not freezing) in Lower Cranberry Creek.

A Water Use Plan for the Walter Hardman Project was completed in 2006 with recommendations proposed by the Walter Hardman Water Use Plan Consultative Committee. The Consultative Committee's primary concern was the lack of a minimum flow to Lower Cranberry Creek and the associated impacts on fish, specifically Rainbow Trout and Kokanee salmon below the diversion dam (BC Hydro, 2004). The Walter Hardman Water Use Planning Consultative Committee designed the Lower Cranberry Creek temperature monitoring program to measure instream temperatures and to record the benefits that a minimum discharge has on high summer temperatures that have been observed in Lower Cranberry Creek. The effect of minimum flows on water temperature in Lower Cranberry Creek was monitored by collecting continuous temperature data over a five year period. The study spanned the entire 10 km length of Lower Cranberry Creek from the point of diversion to the channel mouth at the Columbia River at the Upper Arrow Reservoir. Three monitoring sites were established 2007 in Lower Cranberry Creek: one located downstream of the point of diversion, one near the channel mouth and one midway along the channel. A fourth site located in Upper Cranberry Creek was added in 2009. This site was added to provide background temperatures upstream of the input of the diversion dam and the minimum flow facility.

The results of data analysis showed that while recorded water temperatures in Lower Cranberry Creek over the course of the study do not present lethal conditions to Rainbow Trout, data suggests that summer water temperatures in the mid and upper reaches of Lower Cranberry Creek are below critical levels for Rainbow Trout. Due to periods that temperature loggers were dewatered or not functioning, temperature data cannot be relied on with confidence, especially during the summer months and low flow periods when loggers are more likely to be dewatered. Conversely, based on available data, the 0.1 $m^3s^{-1}$ minimum flow does not maintain stream temperatures above 2$^oC$ during winter months and thus Lower Cranberry Creek temperatures may limit Kokanee egg incubation. Similar to downstream sites, temperatures at Site 4 above the diversion dam fall below 2$^oC$ by the end of November and remain below 2$^oC$ until mid-March. Further, the comparison of water temperatures with daily recorded flow data does not show a strong relationship. A more detailed study with loggers at identified spawning sites and buried in the substrate would be required to fully assess (Appendix 3, Figure 1).

**WHNMON-4 STATUS of OBJECTIVES, MANAGEMENT QUESTIONS AND HYPOTHESES YEAR 5 (2012)**

| Objectives | Management Questions | Management Hypothesis | Year 1-5 (2007-2012) Conclusions |
|---|---|---|---|
| The objective of this monitoring program is to collect continuous water temperature data at three sites in Lower Cranberry Creek over a period of five years to determine if temperatures are suitable for Rainbow Trout rearing and Kokanee egg incubation. | Does a minimum flow affect water temperatures for fish in Cranberry Creek? Specifically, does implementation of a minimum flow release over the diversion dam mitigate warm temperatures during summer and fall and cold temperatures over winter to the benefit of fish in Lower Cranberry Creek? | $H_0$: Operation of the diversion dam to provide minimum flow releases of 0.1 $m^3s^{-1}$ does not provide temperature ranges suitable for Rainbow Trout rearing and Kokanee egg incubation.<br><br>$H_A$: Operation of the diversion dam to provide minimum flow releases of 0.1 $m^3s^{-1}$ provide temperature ranges suitable for Rainbow Trout rearing and Kokanee egg incubation. | Data suggests that summer water temperatures in the mid and upper reaches of Lower Cranberry Creek are below critical levels for Rainbow Trout.<br><br>In winter, the collected data indicates that water column temperatures regularly fall below 2$^o$C in Lower Cranberry Creek. However, a more detailed study with loggers at identified spawning sites and buried in the substrate would be required to fully investigate the potential effects on Kokanee egg incubation.<br><br>The data does not present a clear indication of overall increase or decrease in water temperatures in Lower Cranberry Creek following the construction of the minimum flow facility in 2009. Due to periods that temperature loggers were dewatered or not functioning, temperature data cannot be relied on with confidence, especially during the summer months and low flow periods when loggers are more likely to be dewatered. |

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# 1.0 Introduction

The Walter Hardman Generating Station is located on Cranberry Creek approximately 25 km south of Revelstoke, BC. It was constructed in 1960 to provide power to the city of Revelstoke. Project facilities include the diversion dam, diversion channel, and two diversion control structures, the Walter Hardman headpond, the Walter Hardman dam and the spillway. It is a run-of-river facility with a maximum of up to 4.3 $m^3s^{-1}$ of water being diverted for power generation from the Cranberry Creek system into the Walter Hardman headpond. Water in the dam flows into the penstock and discharges from the powerhouse into the Columbia River at the Upper Arrow Reservoir. Any excess flow spills back into Lower Cranberry Creek over the diversion dam.

The system changed in 2003 when the Coursier Dam, located upstream and providing water storage to the Walter Hardman dam, was decommissioned. The Coursier Dam regulated flows throughout the year, reducing or eliminating natural summer and winter low flow periods. Additionally, a concrete diversion dam located on Upper Cranberry diverts flows into the Walter Headman headpond (Figure 1-1). When discharge in Upper Cranberry Creek falls below 4.3 $m^3s^{-1}$, all flows are directed into the headpond, and input to Lower Cranberry Creek is limited to groundwater and inflow from tributaries located downstream of the diversion dam. Without the flow regulating effects of the Coursier dam and the presence of the concrete diversion dam on Upper Cranberry Creek, Lower Cranberry Creek experiences times with very little to no flow input from Upper Cranberry Creek.

The Cranberry Creek watershed encompasses an area of 145 $km^2$, of which 100 $km^2$ are upstream of the diversion dam (BC Hydro, 2006a). The seasonal flow pattern in the Cranberry Creek system exhibits typical hydrological patterns of the mountain streams in the area with a spring peak flow of snow melt and low flow periods occurring during the winter. Lower Cranberry Creek is approximately 10 km in length, drains into the Upper Arrow Reservoir and supports populations of Rainbow Trout (*Oncorhynchus mykiss*) and Kokanee salmon (*Oncorhynchus nerka*). Kokanee salmon inhabit only the lower reach of Lower Cranberry Creek due to an impassable canyon located between Site 1 and 2 (11 U 429093 5619729) that prevents upstream migration.

A Water Use Plan for the Walter Hardman Project was completed in 2006 with recommendations proposed by the Walter Hardman Water Use Plan Consultative Committee. The Consultative Committee's primary concern was the lack of a minimum flow to Lower Cranberry Creek and the associated impacts on fish, specifically Rainbow Trout and Kokanee salmon below the diversion dam (BC Hydro, 2004). The diversion dam diverts water from Upper Cranberry Creek to flow into the Walter Hardman headpond, prior to which flowed into Lower Cranberry Creek. One of the operating recommendations of the Consultative Committee was the provision of a minimum flow of 0.1 $m^3/s$ over the diversion dam into Lower Cranberry Creek (B.C. Hydro, 2006b). The anticipated benefit of the minimum flow is improved fish habitat, including by mitigation of adverse water temperatures experienced in Lower Cranberry Creek.

The two specific concerns expressed by the Committee are:

1) Warm water temperatures in the upper and middle sections of Lower Cranberry Creek during the summer that may exceed critical levels for Rainbow Trout.

2) Cool water temperatures during the fall and winter in the lower section of Lower Cranberry Creek that may affect the rate of Kokanee egg incubation.

Construction of the minimum flow facility began in April 2008 and was completed within a month. Two subsequent modifications to the facility to achieve the required discharge occurred in late 2008 followed by a year of monitoring through the winter base flow, freshet and low summer flow periods. A final modification was completed in late 2009. In response to recommendations provided within the Water Use Plan and to provide information for future operating decisions, BC Hydro initiated a monitoring program of the Walter Hardman Project. Temperature monitoring in Lower Cranberry Creek is one aspect of the monitoring program and this report documents the five year (2007-2012) temperature effects monitoring program.

The field component of the monitoring program was implemented by the Canadian Columbia River Intertribal Fisheries Commission (CCRIFC) in 2007 and they conducted the field program until 2010 when BC Hydro took over the project. After the field program and initial data analysis, BC Hydro retained Triton Environmental Consultants Ltd. to perform a quality assurance review of the data and results and provide additional analysis.

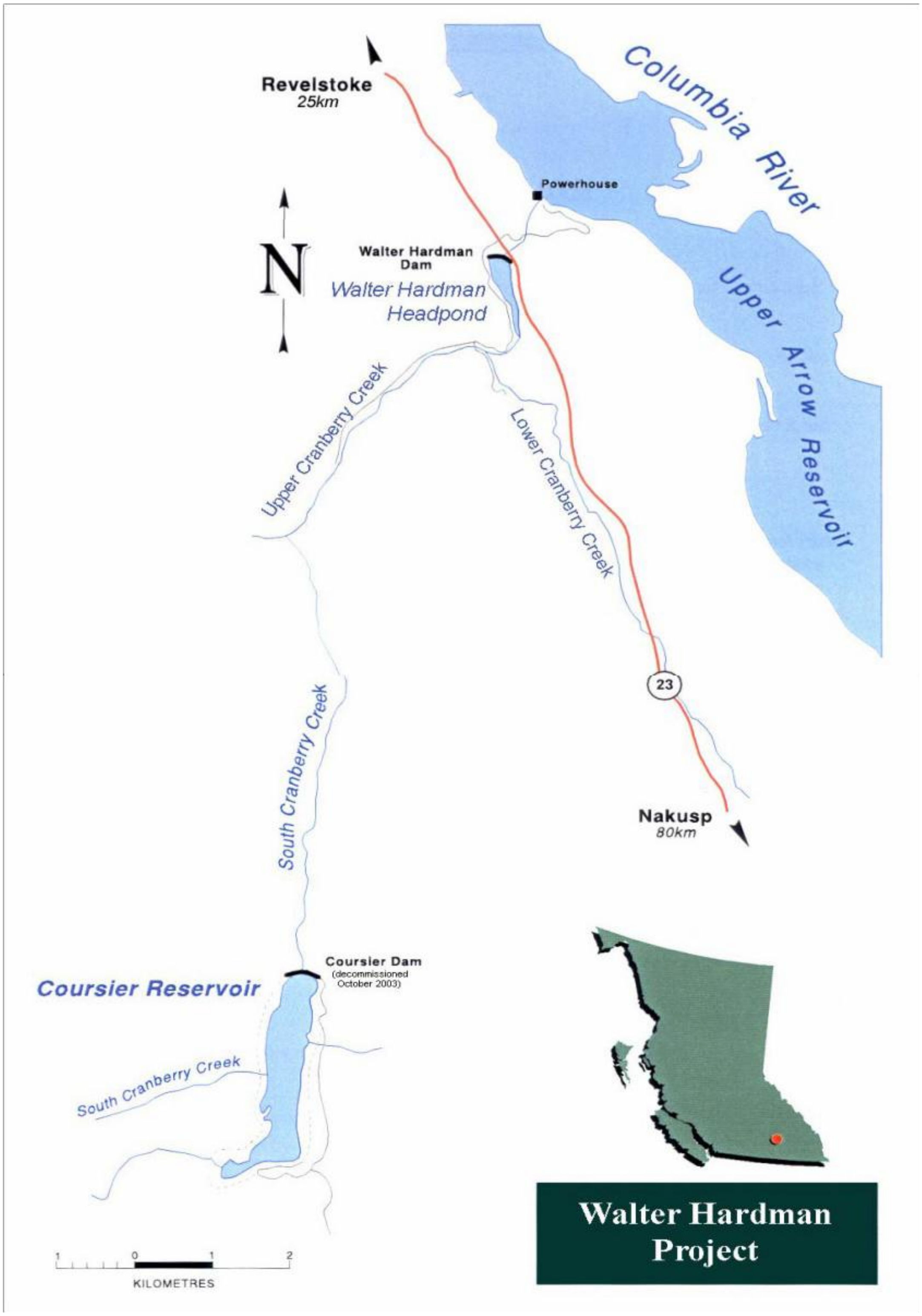


**Figure 1-1**. Map of Walter Hardman Project.
Source: Walter Hardman Project Use Plan, Monitoring Program Terms of Reference, 2006.

# 2.0 Methodology

The methodology for the Lower Cranberry Creek Temperature Effects Monitoring program mirrored the BC Hydro Terms of Reference where appropriate (BC Hydro, 2006b). The field component of the monitoring program was implemented by the Canadian Columbia River Intertribal Fisheries Commission (CCRIFC) from 2007 until 2010 when BC Hydro took over the field component. The general approach to the study was to install continuous temperature monitors at three sites downstream of the diversion dam in Lower Cranberry Creek: the first in Reach 1 (site 1, loggers WHN1 and WHN6), the second in Reach 3 (site 2, loggers WHN2 and WHN5) and the third in Reach 6 (WHN3 and WHN4) (Table 2-1 and Figure 2-1). Late in the second year of sampling (2009), it was determined that a site representing background temperatures was needed and a fourth site located upstream of the diversion dam was added to the project.

**Table 2-1**. Monitoring sites and location descriptions

| Site ID | UTM (NAD 83) | Location |
|---|---|---|
| Site 1 | 11 429965E 56191000N | Downstream near mouth of Lower Cranberry Creek |
| Site 2 | 11 427150E 5622500N | Midway from channel mouth to the diversion dam, upstream of a canyon barrier (barrier to Kokanee) |
| Site 3 | 11 425949E 5625309N | Downstream of concrete diversion dam |
| Site 4 | n/a | Upstream of concrete diversion dam |

## 2.1 Temperature loggers

The CCRIFC installed the temperature loggers after freshet conditions of 2007 on April 27. Two Onset, StowAway® Tidbit Temp Logger (TBI32-05+37 temperature loggers were set at each site (Table 2-2). Each temperature logger was anchored within a 20x20x20 cm cinderblock that was attached to a riparian shrub or tree species by a 7 cm diameter cable. The temperature loggers were further protected from breakage by a 10 cm diameter PVC pipe inserted inside each cinderblock (Photo 1). The temperature loggers were duplicated at each site to assure success of data collection.

**Table 2-2.** Monitoring sites and associated temperature loggers

| Site ID | Logger name |
|---|---|
| Site 1 | WHN1 and WHN6 |
| Site 2 | WHN2 and WHN5 |
| Site 3 | WHN3 and WHN4 - Moved in August of 2007 |
| Site 4 | #2295918, and #2295737 - installed in 2009 |

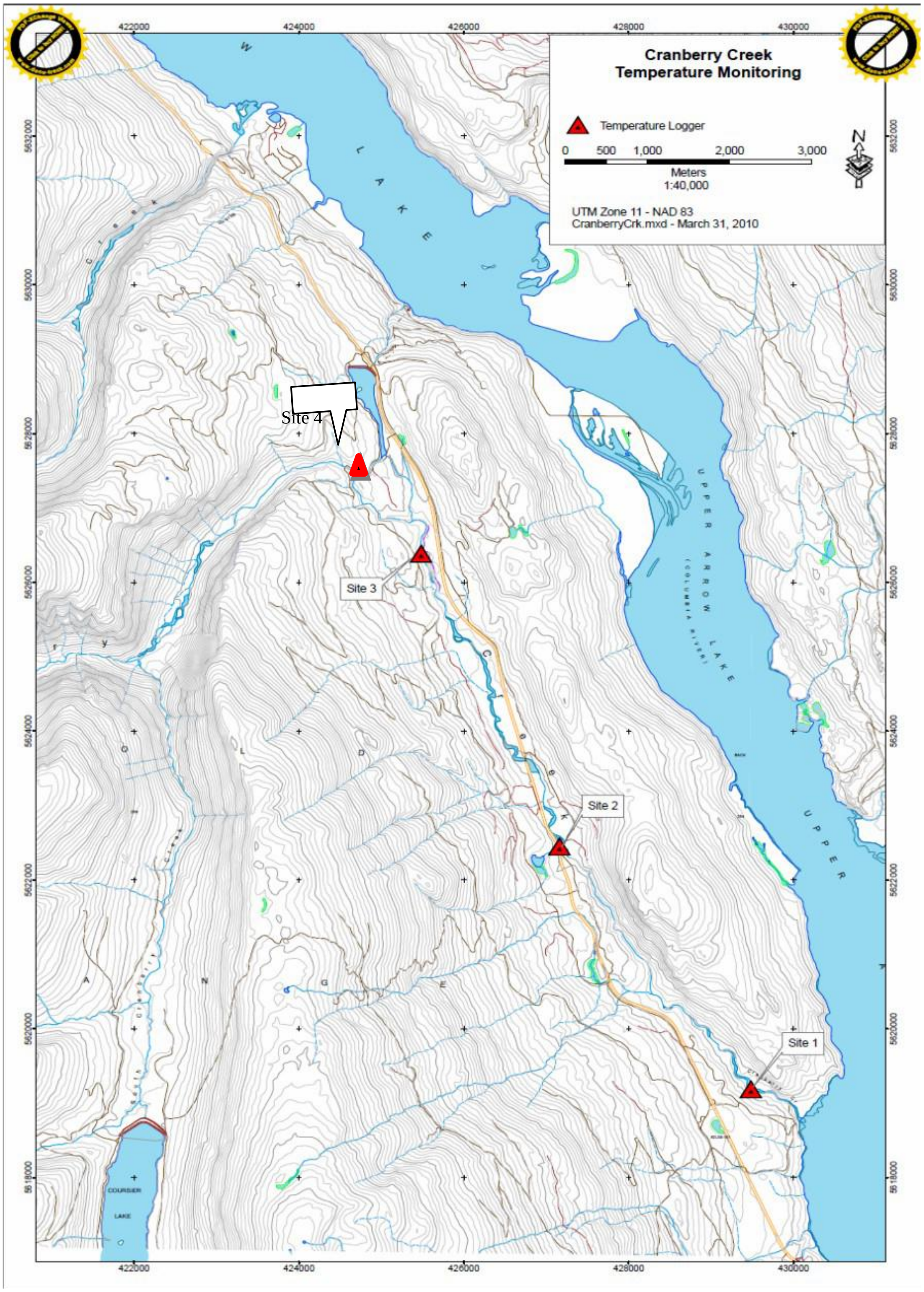


**Figure 2-1.** Map of Lower Cranberry Creek temperature monitoring site locations.

**Photo 1:** Example of a temperature logger secured within a PVC pipe and anchored inside a cinder block. Photo taken September 21, 2009

## 2.2 Site visits

Site visits were planned two to three times a year and timed to occur prior to freshet, during the summer after freshest, and prior to winter freezing in order to reposition the temperature loggers if needed. During site visits equipment was inspected for damage, repaired or replaced if needed, and data was downloaded from the Tidbit Temperature Loggers. Data collection at sites 1, 2, and 3 began on April 27, 2007, and data collection at site 4 began on September 17, 2009. Temperature data was collected at 30 minute intervals, except for loggers WHN2 and WHN6 in 2010, WHN3 in 2010, 2011, and 2012, and both loggers located at site 4, at which data was collected at 60 minute intervals. Function and quality assurance of the loggers was checked during site visits by comparing temperature readings of the logger with a handheld analog thermometer or a digital Radio Shack Precision indoor/outdoor thermometer (model #63-1009A). At each download the temperature loggers, cable, and cinderblock weight were examined to determine if replacement was needed.

## 2.3 Data Analysis

Data downloaded from the Tidbit temperature loggers was entered into a Microsoft Excel spreadsheet for analysis. Data was visually checked for copying errors and line graphs were created in Excel to show all data points recorded, resulting in a clear view of daily minimums and maximums. Results are discussed in Section 3.0 Results. Further analysis of water temperature included a comparison of daily water temperatures with recorded flow data from the WHN monitoring station and the Water Survey of Canada station upstream from the diversion dam and with data obtained during the WHNMON-1 and WHNMON-2 projects (BC Hydro 2012). Flow data at the WHN monitoring station was also compared to temperatures recorded at Site 4 above the diversion dam. The analysis is described in Section 4.0 Discussion.

## 2.4 Data Quality Assurance

When the temperature loggers were downloaded, either a handheld analog alcohol thermometer or a digital Radio Shack Precision indoor/outdoor thermometer (model #63-1009A) was used to conduct quality assurance checks. The results from the quality assurance checks are found in Appendix 1. These checks were done to determine if the loggers were functioning properly. Looking at the data is it hard to determine if loggers were functioning properly due to numerous data gaps and discrepancies between the readings. Discrepancies in temperature readings can be due to the state in which the loggers were found, the accuracy of the temperature logger, or the handheld thermometers being used. For most of the entries the two duplicate temperature loggers at each site had similar temperature readings at the time of the quality assurance checks.

Additional quality assurance review was completed by Triton which included removal of obvious outliers in the temperature data due to dewatering or freezing.

## 2.5 Characteristics of Kokanee and Rainbow Trout

The Consultative Committee were specifically concerned about cool water temperatures during the fall and winter in the lower section of Lower Cranberry Creek impacting Kokanee egg incubation, and summer temperatures in the upper and middle sections of Lower Cranberry Creek exceeding critical levels for Rainbow Trout. Optimal ranges and lethal temperatures for both adult Rainbow Trout and Kokanee egg incubation are presented in Table 2-3.

**Table 2-3.** Temperature range for Rainbow Trout and Kokanee salmon

| | Spawning (°C) | Eggs (°C) | Juvenile (°C) | Adult (°C) |
|---|---|---|---|---|
| Rainbow trout | Optimal 10-15.5[1] | Optimal 11[2]<br>Tolerable 2-20[2] | Optimal 10-14[2]<br>Tolerable 0-24[2] | Optimal 10-14[2]<br>Tolerable 0-28[2]<br>Lethal 24[3] |
| Kokanee salmon | Optimal 10.6-12.8 (sockeye)[1] | Optimal 6[2]<br>Optimal 4-13[1]<br>Tolerable 2-15[2] | Optimal 15[2]<br>Tolerable 6.7-24.4[2] | Optimal 10-15[3]<br>Tolerable 6.7-24.4[2]<br>Lethal 24.4[3] |

Source: MOE, 2001[1], Ford et al., 1995[2], Roberge et al., (2002)[3].

Spawning characteristics of different populations of Kokanee salmon vary from one stream to the next, with some populations becoming better suited to the cold water temperatures of the natal stream, and other populations becoming better adapted to warmer conditions experienced in the natal streams (Bjornn and Reiser in Meehan, 1991). While population-specific differences exist, the phenomenon that embryos develop at a faster rate with increased incubation temperatures is equally true for all Kokanee (Garrett, Bennett, Frost, 1998; Murray, McPhail, and Rosenau, 1991).

Mature Kokanee return to streams from August to December to spawn. Some Kokanee will spawn in areas of groundwater upwelling, which can be 2-3°C warmer than surface flow temperatures (Garrett et al., 1998; Reiser and Wesche, 1979). The benefits of spawning in areas of upwelling are higher incubation temperatures, accelerated rates of development and protection of embryos from freezing which may increase the survival of fry recruitment (Garrett et al., 1998). Eggs remain protected under gravels through the winter hatching between late March and early May (BC Ministry of Fisheries).

The temperature tolerance range for Kokanee egg incubation is 2-15°C, where Ford et al. (1995) determined the optimal temperature to be 6°C, and Hendry et al. found the highest survival rates during laboratory tests set at 5°C and 9°C. The survival of eggs during the laboratory test at 12.5°C showed significantly less survival. Other than Ford et al.'s reference to the lower temperature limit, the majority of literature reviewed discussing temperature constraints focused on upper limits, not lower limits. However, despite this it seems reasonable to assume that maintaining water temperatures in Lower Cranberry Creek above 2°C throughout the winter will reduce the risk to incubating eggs.

In regards to Rainbow Trout rearing, Ford et al. (1995) indicate that the upper temperature tolerance range of adult Rainbow Trout is $28^{o}$C, while Roberge et al. (2002) indicates that $24^{o}$C is lethal to Rainbow Trout. The optimal range is $10\text{-}14^{o}$C indicated by Ford et al. Even if Rainbow Trout can survive in $28^{o}$C, the dissolved oxygen will be very low, and the fish would be stressed. For this report, the more conservative value of $24^{o}$C is used as a reference. Rainbow Trout spawn in the spring, eggs hatch and alevins grow into fry within about 8 weeks depending on water temperatures. Therefore, Rainbow Trout fry and adults are in streams during the hottest summer temperatures. Both juvenile and adult life stages show similar optimal and tolerable temperatures (Table 2-3).

# 3.0 Results

The water level of Lower Cranberry Creek fluctuates throughout the year as do most mountain streams. Flows in Lower Cranberry Creek are further influenced by the diversion of water into the Walter Hardman Dam at the diversion dam (Photo 2 and 3). A decrease in discharge causes water velocities to decrease (Triton 2012a, b), allowing the water temperature to warm or cool depending on the ambient air temperatures. During summer months, pooled water will increase in temperature quicker than flowing water. Prior to the implementation of the minimum flow discharge in 2008 water did not flow over the diversion dam into Lower Cranberry Creek when flows in Upper Cranberry Creek were less than 4.3 $m^3s^{-1}$. Minimum flows at the diversion dam were implemented in late 2008. Therefore, water temperature data collected in 2007 and 2008 represent pre-minimum flow conditions, and data collected in the period of 2009 - 2012 represent post-minimum flow conditions.

**Photo 2.** Water flowing over the Walter Hardman diversion dam. View from the left to the right bank. Photo taken October 28, 2011

**Photo 3.** Dry conditions at the diversion dam. View from Lower Cranberry Creek downstream of the diversion dam facing upstream. Upper Cranberry Creek is located at the toe of the treeline and flows towards photo right into the Walter Hardman headpond. The minimum flow facility consists of two drywell intakes (perforated concrete cylinders) that are located on the right bank upstream from the diversion dam.
Photo taken September 2, 2011.

The water level in Lower Cranberry Creek was highly variable during the monitoring program and on at least seven occasions temperature loggers were discovered out of the water or were unable to be found during site visits. Additionally, bedload movement and a shifting thalweg impacted loggers on at least two occasions. During the five year monitoring program sites were visited and data was downloaded 11 times not including project start-up and shutdown. At all 11 site visits there was at least one site which was found to have a dewatered or broken logger. When a logger was found dewatered, malfunctioning, buried or lost, the logger was repositioned in the stream channel or replaced with a new logger. Table 3-1 summarizes dates sites were visited, the state in which loggers were found, and the action taken at the time of the site visit. If the state of the logger was not given, it is assumed the logger was functioning properly and data was downloaded.

**Table 3-1.** Summary of monitoring program site visits and the state of data loggers

| Date of Site Visit | State of Data Logger | Action Taken |
|---|---|---|
| April 27, 2007 | | • Loggers deployed |
| August 16, 2007 | • WHN1, WHN6 dewatered | • WHN1, WHN6 repositioned in channel<br>• WHN3, WHN4 relocated |
| May 9, 2008 | • WHN1, WHN6 functioning properly | • WHN1, WHN6 downloaded |

| Date of Site Visit | State of Data Logger | Action Taken |
|---|---|---|
| | • WHN2, WHN5 functioning properly | • WHN2, WHN5 downloaded<br>• WHN3 downloaded, WHN4 replaced |
| August 6, 2008 | • WHN1, WHN6 dewatered<br>• WHN2 buried in sand, WHN5 casing damaged<br>• WHN3, WHN4 dewatered | • WHN1, WHN6 repositioned further upstream<br>• WHN2 unburied, WHN5 casing replaced; both downloaded<br>• WHN3, WHN4 not downloaded and repositioned |
| October 27, 2008 | • WHN1 dewatered<br>• WHN2, WHN5 functioning properly<br>• WHN3, WHN4 one dewatered, one not | • WHN2, WHN5 downloaded<br>• WHN3, WHN4 downloaded |
| August 31, 2009 | • WHN1, WHN6 functioning properly<br>• WHN2, WHN5 functioning properly<br>• WHN3 dewatered | • WHN1, WHN6 downloaded, redeployed |
| November 2, 2009 | • WHN1, WHN6 functioning properly<br>• WHN2, WHN5 functioning properly<br>• WHN4 functioning properly, WHN3 not functioning properly | • WHN1, WHN6 downloaded, redeployed<br>• WHN2, WHN5 downloaded, redeployed<br>• WHN3 not downloaded, WHN4 downloaded, redeployed. |
| May 7, 2010<br>(BC Hydro takeover) | • WHN1 functioning properly, WHN6 not functioning<br>• WHN2, WHN5 functioning properly<br>• WHN3, WHN4 could not be found | • WHN1 downloaded, redeployed, WHN6 data not retrieved<br>• WHN3 not downloaded |
| May 10, 2010 | • WHN3 not functioning properly – data lost | • WHN6 replaced with new logger<br>• WHN3 replaced with new logger |
| July 28, 2010 | • WHN1 functioning properly, WHN6 dewatered<br>• WHN2, WHN5 functioning properly<br>• WHN3, WHN4 functioning properly | • WHN1 downloaded, redeployed, WHN6 repositioned<br>• WHN2, WHN5 downloaded, redeployed<br>• WHN3, WHN4 downloaded, redeployed |
| November 17, 2010 | • One of WHN2 or WHN5 dewatered, the other in stream | |
| 2011 – pre and post freshet flows | • Data lost for all sites (mid-November 2010 to | |

| Date of Site Visit | State of Data Logger | Action Taken |
|---|---|---|
| | early May 2011) | |
| September 2, 2011 | • WHN1 functioning properly, WHN6 lost<br>• WHN2 dewatered, WHN5 lost<br>• WHN3, WHN4 dewatered | • WHN1 data downloaded and redeployed<br>• WHN5 replaced<br>• WHN3, WHN4 downloaded, repositioned |
| September 16, 2011 | | • WHN6 replaced |
| September 18, 2012 | | • All loggers removed |

All data downloaded from the temperature loggers is presented in line graphs for each site, for each year (Appendix 2). When the two loggers deployed at a site were set to collect data on the same interval, results from both of the loggers are presented in one figure. When loggers at a site were set to collect data at different intervals, data from each logger is presented in two figures. Presenting data from two loggers in one figure allows for a visual comparison of data. If one logger became dewatered, and the second remained wetted, then the temperature data is still useful. It should be noted that data from all loggers at Sites 1 – 3 was lost for the period from mid-November 2010 to early May 2011. A summary for each site and a representative figure are presented below:

**Site 1:** Based on available information, the loggers at Site 1 were found functioning and successfully downloaded 55% of the time, found dewatered and repositioned 27% of the time, and the logger was found broken or data was lost 18% of the time. Figure 3-1 shows water temperatures recorded at Site 1 (WHN1 and WHN6) from May 4, 2011 to December 31, 2011. Data is available for the following periods from the loggers at Site 1:

**WHN1**

- April 27, 2007 to December 31, 2007
- January 1, 2008 to December 31, 2008
- January 1, 2009 to December 31, 2009
- January 10, 2010 to November 17, 2010
- May 4, 2011 to December 31, 2011
- January 1, 2012 to September 19, 2012

**WHN6**

- April 27, 2007 to December 31, 2007
- January 1, 2008 to December 31, 2008
- January 1, 2009 to December 31, 2009
- January 1, 2010 to November 17, 2010
- September 16, 2011 to December 31, 2011
- January 1, 2012 to April 19, 2012

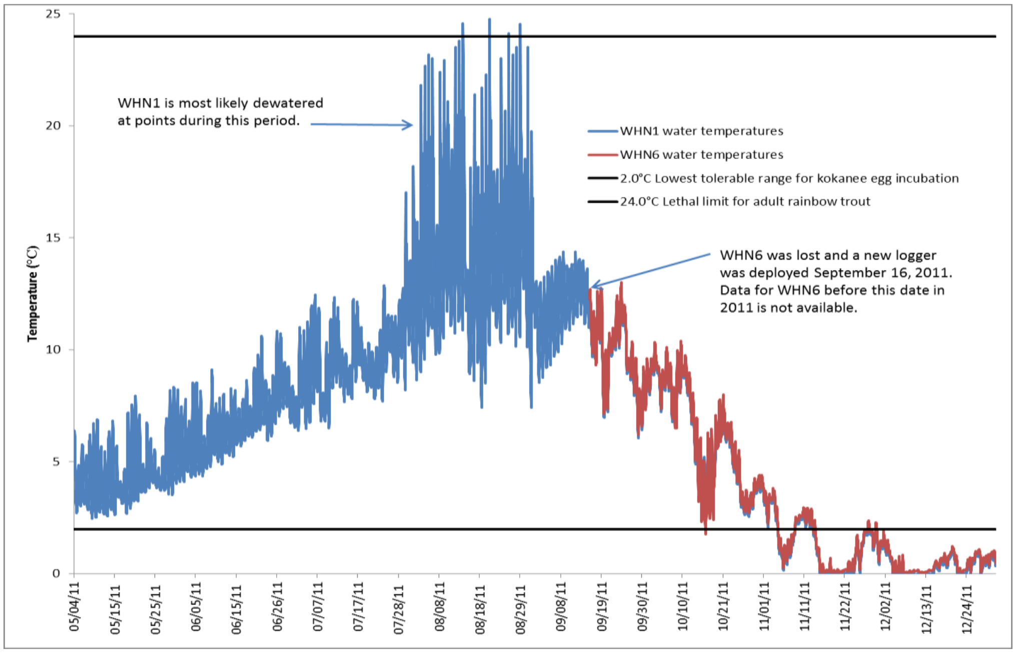


**Figure 3 1.** Water temperatures recorded at Site 1 from May 4 to December 31, 2011

**Site 2:** The loggers at Site 2 were found functioning and successfully downloaded 68% of the time, found dewatered and repositioned 9% of the time, and either found broken or data was lost 23% of the time. Available data begins August 16, 2007 for the two loggers at site 5. Figure 3-2 shows water temperature data recorded at Site 2 (WHN2 and WHN5) from May 4 to December 31, 2011. Data is available for the following periods from the loggers at Site 2:

**WHN2**

- August 16, 2007 to December 31, 2007
- January 1, 2008 to December 31, 2008
- January 1, 2009 to December 31, 2009
- May 20, 2010 to June 7, 2010; July 28, 2010 to August 15, 2010
- May 4, 2011 to December 31, 2011
- January 1, 2012 to September 19, 2012

**WHN5**

- August 16, 2007 to December 31, 2007
- January 1, 2008 to December 31, 2008
- January 1, 2009 to June 8, 2009; September 2, 2009 to December 31, 2009
- January 1, 2010 to November 17, 2010
- May 13, 2011 to December 31, 2011
- January 1, 2012 to September 19, 2012

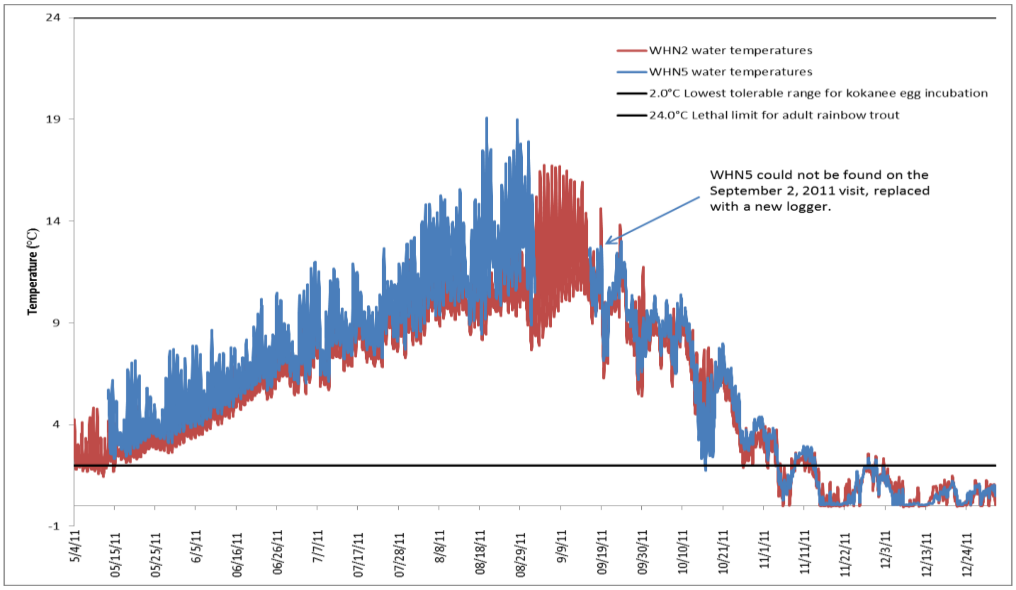


**Figure 3-2.** Water temperatures recorded at Site 2 from May 4 to December 31, 2011

**Site 3:** The loggers at Site 3 were found functioning and successfully downloaded 36% of the time, found dewatered and repositioned 23% of the time, and found either broken or data was lost 41% of the time. Figure 3-3 shows water temperature data recorded at Site 3 (WHN3 and WHN4) from January 1 to October 27, 2008. Available data for WHN3 begins August 24, 2007 and for WHN4 on May 9, 2008. Data is available for the following periods from the loggers at Site 3:

**WHN3**

- August 24, 2007 to December 29, 2007
- January 1, 2008 to October 18, 2008
- May 20, 2010 to November 11, 2010
- May 4, 2011 to December 31, 2011
- January 1, 2012 to September 12, 2012

**WHN4**

- May 9, 2008 to October 27, 2008
- March 19, 2009 to November 3, 2009
- May 20, 2010 to November 11, 2010
- May 4, 2011 to December 31, 2011
- January 1, 2012 to September 12, 2012

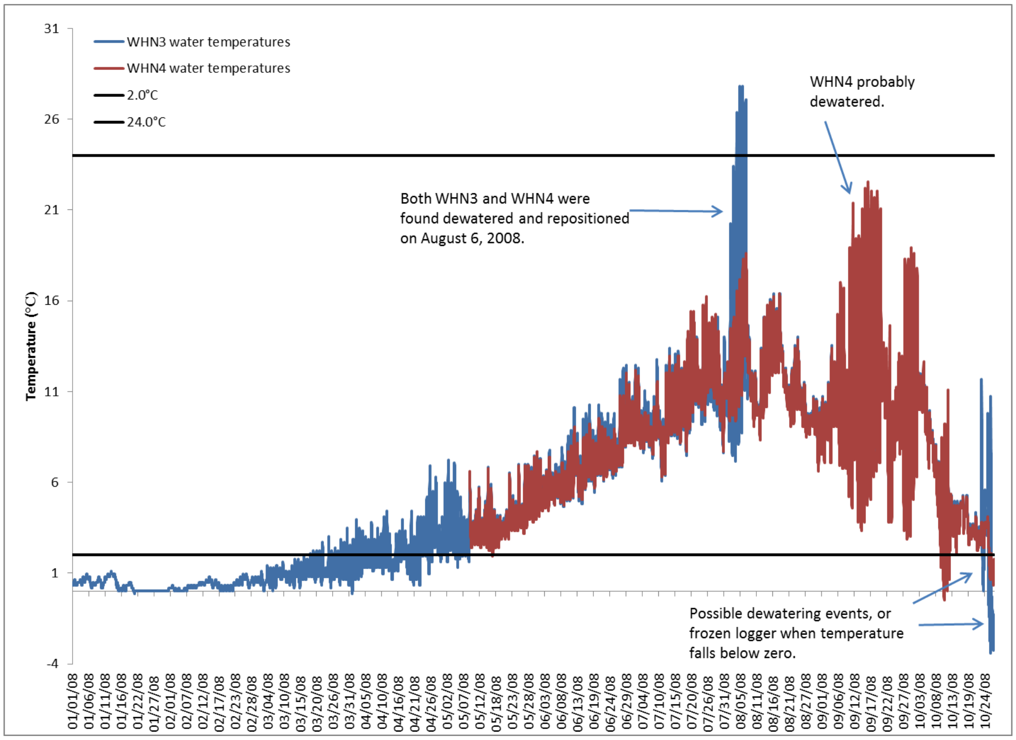


**Figure 3-3.** Water temperatures recorded at Site 3 from January 1 to October 27, 2008

## 3.1 Data Analysis

The objective of this monitoring program was to determine the potential benefits of minimum flows on adverse water temperatures in lower Cranberry Creek. In particular, to determine the potential effects of the proposed minimum flow release on critical upper temperatures for Rainbow Trout in the summer and on low temperatures during the fall and winter that may affect the rate of Kokanee egg incubation (BC Hydro September, 2006). As discussed and shown in the figures from the previous section, not all data sets span an entire year and the only full years of data are 2008 and 2009 for Site 1 and Site 2. Seasonal mean, max, and min for the warmest (July to August) and coldest (December to February) months were calculated. However, there are several years when data is missing during these months (due to data loss, logger malfunction, or unknown) and water temperature data for Site 3 is lacking large portions of data, particularly during the winter months.

While the exact date that a logger became dewatered is not apparent when viewing the data set, inferences can be made by considering the diurnal variation of air temperatures compared to diurnal variations of stream temperatures on the line graphs. The diurnal variations of air temperatures are greater than the diurnal variation in stream temperatures, especially on hot summer days. This characteristic makes it possible to view periods when the loggers are likely out of the water when illustrated on the line graphs. Hourly air temperature data for May 2011 to October 2011 was plotted on Figure 3-4 (Figure 6 in Appendix 2). It can be seen from this graph that WHN1 was likely out of the water for the month of August since the diurnal variation in temperature becomes more pronounced and is similar to that of the graphed air temperature. The logger is probably recording air temperatures and not water temperatures at this point. The logger was redeployed on

September 2, 2011 and the diurnal variation started to become less pronounced as it most likely began recording water temperature again.

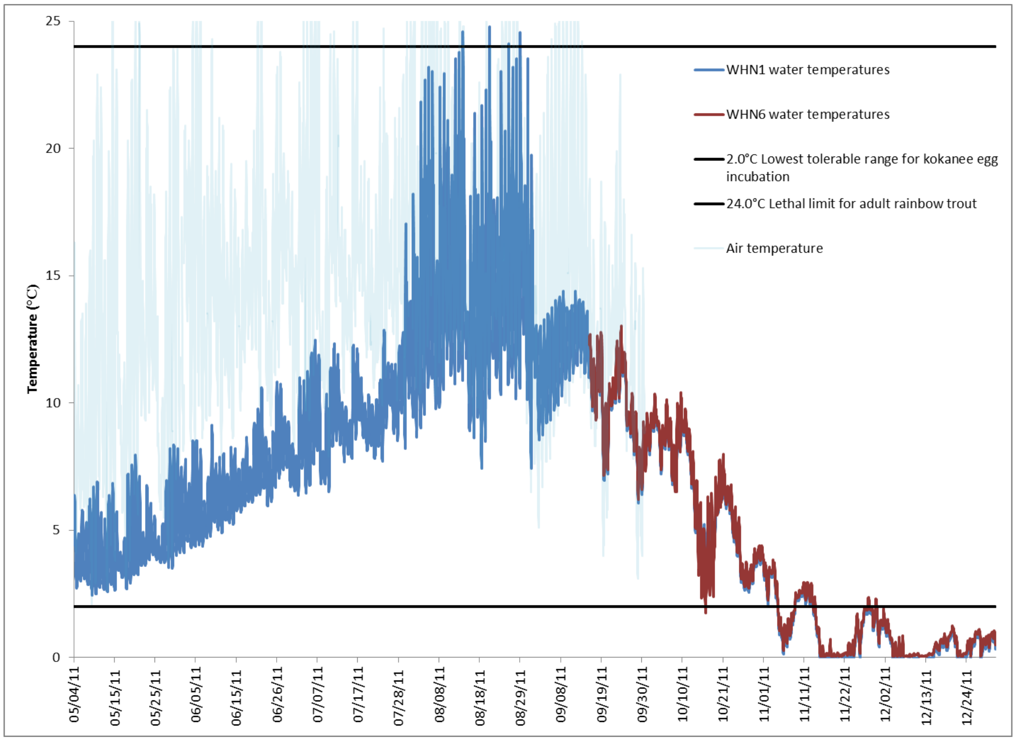


**Figure 3-4.** Water and air temperatures recorded at Site 1 from May to December 2011

Exceedances that were likely caused by dewatering events or malfunction of the loggers were not included in the calculations of seasonal mean, min, and max values at each site to the maximum extent practicable. Dewatering events often occurred during the warmer months, including July and August, reducing confidence in the water temperature data during these critical seasonal months. Temperatures below zero (indicating a frozen logger) during the winter critical months were also not included in the calculations. A summary of likely dewatering events or logger malfunctions is presented below:

**Site 1**
**WHN1**

- 2011 – likely dewatered for the majority of August

**WHN6**

- 2009 – likely dewatered for the majority of August

**Site 2**
**WHN2**

- 2010 – data only available July 28 – August 15

**WHN5**

- 2008 – likely dewatered for a few days at the end of July

- 2009 – no data for July and August

**Site 3**
**WHN3**
- 2010 – likely dewatered second half of August
- 2012 – likely dewatered beginning July 26 until loggers removed in September

**WHN4**
- 2009 – likely malfunction beginning around August 16
- 2011 – likely dewatered beginning August 17
- 2012 – likely dewatered beginning August 1 until loggers removed in September

Analysis of the data showed that temperatures fluctuated with the seasons. When looking at the graphs (Appendix 2) it is clear that the coldest temperatures occurred in the winter (December to February) during Kokanee spawning and egg incubation, and the warmest temperatures occurred in the summer months (July and August) during Rainbow Trout rearing. Where data was available, seasonal mean, max, and min for all sites (including Site 4) were calculated and these values for July to August are shown in Table 3-2 and values for December to February are shown in Table 3-3.

**Table 3-2.** Mean, maximum and minimum temperatures in °C for each logger July to August

| | Site 1 | | Site 2 | | Site 3 | | Site 4 | |
|---|---|---|---|---|---|---|---|---|
| | WHN1 | WHN6 | WHN2 | WHN5 | WHN3 | WHN4 | 2295737 | 2295918 |
| **July - Aug 2007** | Mean: 13.02<br>Min: 7.07<br>Max: 19.89 | Mean: 12.92<br>Min: 7.37<br>Max: 19.32 | N/A, data begins 8/16/07 | N/A, data begins 8/16/07 | N/A, data begins 8/24/07 | N/A, no data | N/A, data begins Sept 2009 | N/A, data begins Sept 2009 |
| **July - Aug 2008** | Mean: 12.11<br>Min: 6.78<br>Max: 18.99 | Mean: 12.61<br>Min: 6.22<br>Max: 21.76 | Mean: 11.75<br>Min: 6.79<br>Max: 18.43 | Mean: 11.35<br>Min: 6.23<br>Max: 20.26 | Mean:10.78<br>Min: 6.08<br>Max: 16.38 | Mean: 11.08<br>Min: 6.31<br>Max: 18.62 | N/A, data begins Sept 2009 | N/A, data begins Sept 2009 |
| **July - Aug 2009** | Mean: 13.51<br>Min: 6.78<br>Max: 18.39 | Mean: 13.17<br>Min: 7.08<br>Max: 17.82 | Mean: 12.97<br>Min: 5.92<br>Max: 20.84 | N/A, no data | N/A, no data | Mean: 11.91<br>Min: 6.39<br>Max: 16.7 | N/A, data begins Sept 2009 | N/A, data begins Sept 2009 |
| **July - Aug 2010** | Mean: 13.1<br>Min: 6.99<br>Max: 17.7 | Mean: 13.41<br>Min: 6.99<br>Max: 19.98 | Mean: 14.01<br>Min: 9.85<br>Max: 20.29* | Mean: 12.57<br>Min: 6.40<br>Max: 21.77 | Mean: 11.89<br>Min: 6.13<br>Max: 20.17 | Mean: 11.24<br>Min: 4.97<br>Max: 17.84 | Mean:10.62<br>Min: 5.85<br>Max: 15.56 | Mean: 10.62<br>Min: 5.87<br>Max: 15.56 |
| **July - Aug 2011** | Mean: 9.75<br>Min: 6.38<br>Max: 18.2 | N/A, no data | Mean: 9.21<br>Min: 5.44<br>Max: 13.26 | Mean: 10.66<br>Min: 6.00<br>Max: 19.08 | Mean: 9.47<br>Min: 5.77<br>Max: 15.58 | Mean: 9.44<br>Min: 5.72<br>Max: 16.84 | Mean: 9.21<br>Min: 5.44<br>Max: 13.26 | Mean: 9.28<br>Min: 5.37<br>Max: 13.47 |
| **July - Aug 2012** | Mean: 13.46<br>Min: 6.66<br>Max: 19.06 | N/A, no data | Mean: 11.34<br>Min: 6.08<br>Max: 17.45 | Mean: 13.45<br>Min: 6.66<br>Max: 19.05 | Mean: 9.17<br>Min: 5.87<br>Max: 13.16 | Mean: 9.77<br>Min: 5.85<br>Max: 18.39 | N/A, no data | Mean: 10.29<br>Min: 5.61<br>Max: 15.10 |

**Table 3-3.** Mean, maximum and minimum temperatures in °C for each logger December to February

| | Site 1 | | Site 2 | | Site 3 | | Site 4 | |
|---|---|---|---|---|---|---|---|---|
| | WHN1 | WHN6 | WHN2 | WHN5 | WHN3 | WHN4 | 2295737 | 2295918 |
| **Dec 2007 - Feb 2008** | Mean: 0.34<br>Min: 0.04<br>Max: 1.23 | Mean: 0.46<br>Min: 0.06<br>Max: 1.54 | Mean: 0.52<br>Min: 0.04<br>Max: 1.83 | Mean: 0.60<br>Min: 0.06<br>Max: 1.85 | Mean: 0.48<br>Min: 0.01<br>Max: 1.13 | N/A,<br>no data | N/A, data begins Sept 2009 | N/A, data begins Sept 2009 |
| **Dec 2008 - Feb 2009** | Mean: 0.54<br>Min: 0.04<br>Max: 3.01 | Mean: 0.66<br>Min: 0.06<br>Max: 3.32 | Mean:0.56<br>Min: 0.03<br>Max: 2.72 | Mean: 0.43<br>Min: 0.03<br>Max: 2.61 | N/A,<br>no data | N/A,<br>no data | N/A, data begins Sept 2009 | N/A, data begins Sept 2009 |
| **Dec 2009 - Feb 2010** | Mean: 1.19<br>Min: 0.024<br>Max: 3.89 | N/A,<br>no data | N/A,<br>no data | Mean: 1.97<br>Min: 0.02<br>Max: 3.72 | N/A,<br>no data | N/A,<br>no data | Mean: 0.65<br>Min: 0.02<br>Max: 2.18 | N/A,<br>no data |
| **Dec 2010 - Feb 2011** | N/A, no data | N/A,<br>no data | N/A,<br>no data | N/A,<br>no data | N/A,<br>no data | N/A,<br>no data | N/A,<br>no data | N/A,<br>no data |
| **Dec 2011 - Feb 2012** | Mean: 0.54<br>Min: 0.02<br>Max: 1.91 | Mean: 0.71<br>Min: 0.02<br>Max: 1.75 | Mean: 0.59<br>Min: 0.02<br>Max: 2.61 | Mean: 0.54<br>Min: 0.02<br>Max: 1.91 | Mean: 0.42<br>Min: 0.02<br>Max: 1.34 | Mean: 0.43<br>Min: 0.02<br>Max: 1.29 | Mean: 0.40<br>Min: 0.02<br>Max: 1.72 | Mean: 0.59<br>Min: 0.02<br>Max: 1.72 |

It should be noted that maximum temperatures during the summer season could still be capturing air temperatures and not reflect actual water temperatures. Conversely, the consistent recorded minimum of 0.02°C at all sites during the winter season could suggest logger malfunction or partially frozen conditions and possibly not reflect actual water temperature.

# 4.0 Discussion

## 4.1 Kokanee

Considering the difficulties during the project with temperature loggers becoming dewatered or frozen, equipment malfunctioning or lost data and the reduced confidence associated with these factors, conclusions can only be inferred from the data. Data show that water column temperatures regularly drop below 2$^{o}$C during the winter months at all sites, well below the optimal range lower limit of 6°C, and often shows that the logger is frozen. Frozen loggers are illustrated by a flat horizontal line at 0$^{o}$C or where temperatures dropped below 0$^{o}$C. Periods below 2$^{o}$C were experienced at all sites including Site 4, the control site. At most sites temperatures begin to fall below 2$^{o}$C mid-November and do not consistently rise above 2$^{o}$C until mid-March. Data collected in 2010 from Site 1 (WHN6), and Site 3 in 2010 (WHN3 and WHN4) do not drop below 2$^{o}$C but data was not available for the entire winter (Figures 5, 16 and 17 in Appendix 2).

Due to the barrier to Kokanee located between Site 1 and 2, water temperatures at Site 1 are the most important for Kokanee egg incubation. However, the loggers were not necessarily installed at egg incubation sites and micro-habitat conditions at redd locations could help mitigate the effects of low temperature. For example, as previously discussed, areas of groundwater upwelling may provide more favourable incubation conditions and are often 2-3°C warmer than the water column temperatures. Logger data is also representative of surface conditions and not necessarily conditions within the gravel.

## 4.2 Rainbow Trout

Sites 2 and 3 represent the middle and upper reaches of Lower Cranberry Creek, which are the areas of concern to exceed critical temperatures for Rainbow Trout during summer months. While most of the figures show data exceeding the 24$^{o}$C reference line, the exceedances appear to be during periods when loggers were dewatered as the diurnal variation is large at those points. As much as possible, exceedances or outliers that were likely caused by dewatering events or malfunctioning loggers were not included in the calculations of seasonal mean, min, and max values for each site. Dewatering events often occurred during the warmer months, including July and August, reducing confidence in the water temperature data during these critical months.

Average summer high temperatures observed at Site 4 (control site) appear to be around 15$^{o}$C, whereas average seasonal summer high temperatures observed at Site 1, 2, and 3 in Lower Cranberry Creek range between 9$^{o}$C and 14$^{o}$C. However, average seasonal temperatures in Lower Cranberry Creek are difficult to determine with confidence due to temperature loggers becoming dewatered, equipment malfunctioning or lost data during the course of the study. Despite this, the data that is available does not suggest that lethal temperatures are experienced although temperatures above the optimal range do occur.

## 4.3 Effects of Discharge on Water Temperature

The comparison of water temperatures with daily recorded flow data from both WHN monitoring station and the Water Survey of Canada station do not show a strong relationship (Appendix 3, Figure 1). If discharge directly affected the average daily water temperature, water temperature would be expected to drop as discharge increased. The high variability of stream flow and periods of missing data made it challenging to determine an obvious trend. Further analysis over a smaller timeframe did show an indirect relationship between discharge and temperature, however, this trend was not consistent throughout the timeframe assessed (Figure 4-1; Appendix 3, Figure 2). The analysis also considered data from the WHNMON#1 and WHNMON#2 projects (Triton 2012 a,b) because in the absence of a discharge monitoring system at the diversion dam itself, data on timing of spills was only available for the days discharge was measured. Although, the daily average temperature appeared to be highest when no spilling was occurring (early September 2011) and a drop in temperature was observed (mid-September 2011) when spilling was known, corresponding with the highest discharge recorded downstream, we cannot confidently report this trend is solely due to changes in discharge (Appendix 3, Figure 2). The trend is not shown in mid to late October during a moderate flow downstream (dam spilling), rather the temperature appears to directly follow the discharge. Further studies with increased data retrieval frequency of both water and air temperatures, and discharge would be required to strengthen this dataset. However this type of assessment and analysis was beyond the scope of the study.

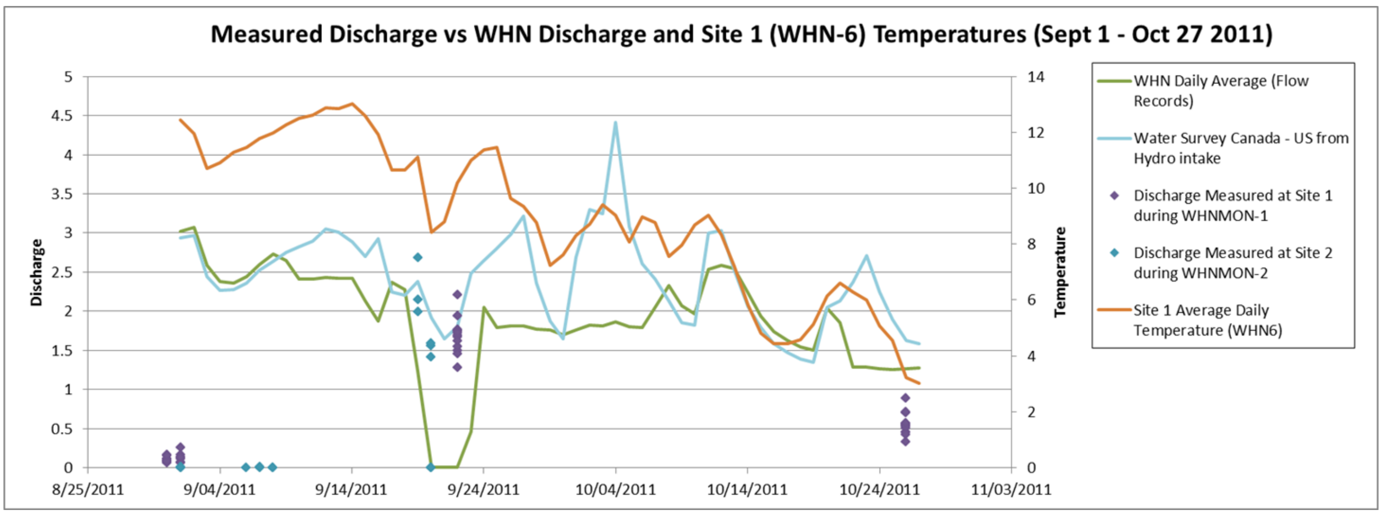

**Figure 4-1.** Measured discharge vs. WHN discharge and Site 1 (WHN6) temperatures September 1 to October 27, 2011

Water temperatures recorded at Site 4, which is upstream of the diversion structure, were compared with hourly recorded discharge data available from BC Hydro WHN monitoring station for the period from January 1, 2012 to September 18, 2012. As previously discussed, recorded water temperatures regularly drop below 2$^{o}$C during the winter months at all sites, including Site 4. As shown in Figure 4-2 (Appendix 3, Figure 3), water temperatures and discharge at Site 4 do not show a strong relationship. Water temperatures remain below 2°C until the end of March and discharge is also low during this time. Isolated spikes in discharge during February do not appear to have an impact on water temperatures. As flows increase into spring freshet, water temperatures also begin to increase. Isolated spikes in discharge still do not appear to have an influence on water temperature during these periods. Discharge begins to decrease at the beginning of July while water temperatures continue to increase and start to fall near the end of August. Due to the cold water temperatures recorded at Site 4 located upstream of the diversion dam, this suggests these water temperatures could be reflective of the natural, pre-disturbance conditions in the system.

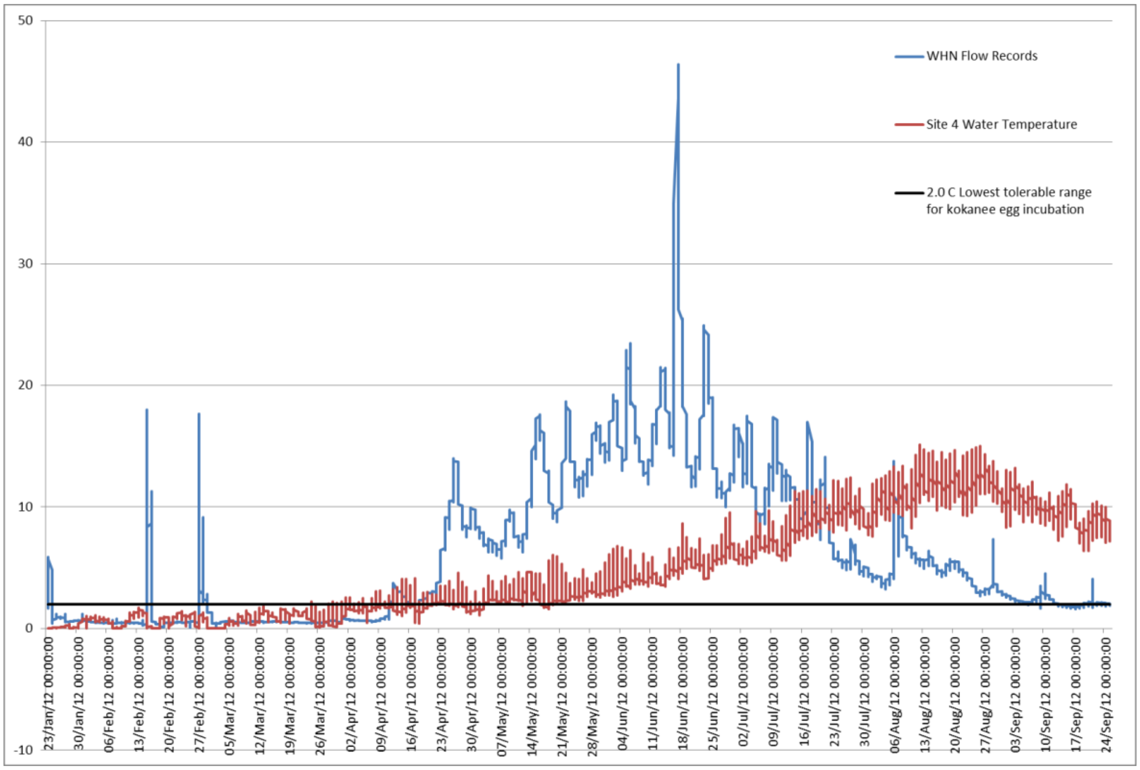


**Figure 4-2.** WHN discharge vs. Site 4 temperatures January 1, 2012 to September 18, 2012

# 5.0 Conclusion

The objective of this monitoring program was to determine the potential benefits of minimum flows on adverse water temperatures in lower Cranberry Creek. In particular, to determine the potential effects of the proposed minimum flow release on critical upper temperatures for Rainbow Trout in the summer and on low temperatures during the fall and winter that may affect the rate of Kokanee egg incubation (BC Hydro September, 2006).

Lack of continuous year-round data does not allow for comparison of data pre-vs. post- with certainty. However, analyzing the data that is available there is no indication of an overall pattern that shows the maximum yearly temperatures have either decreased or increased in Lower Cranberry Creek downstream of the Walter Hardman diversion dam after the installation of the minimum flow structure. The seasonal minimum temperatures are not noticeably warmer or colder in post minimum flow conditions compared to both pre minimum flow conditions and the temperatures upstream of the diversion dam.

Based on available data, the 0.1 $m^3s^{-1}$ minimum flow does not maintain stream temperatures above $2^oC$ during winter months and thus Lower Cranberry Creek temperatures may limit Kokanee egg incubation. However, a more detailed study with loggers at identified spawning sites and buried in the substrate would be required to make a full assessment. Temperatures at Site 4 above the diversion dam also fell below $2^oC$ during winter months. Due to the cold water temperatures recorded at Site 4 upstream of the diversion dam, it would not be expected that increased flows would improve incubation conditions in the lower reaches during winter months. In the mid and upper reaches of Lower Cranberry Creek, recorded temperatures were often above $24^oC$ but these appear to occur during periods when the loggers were dewatered and are recording air temperatures. While recorded water temperatures in Lower Cranberry Creek over the course of the study do not present lethal conditions to Rainbow Trout, data suggests that summer water temperatures in the mid and upper reaches of Lower Cranberry Creek do exceed the optimal range for Rainbow Trout.

The management question put out for this monitoring program still cannot be clearly answered. This is due to the uncertainty of the accuracy of the temperature data itself. Further, the flow conditions within Lower Cranberry Creek vary immensely throughout the year with high freshet flows when water spills over the diversion dam, to low flows during the summer and winter with only groundwater and local inflows downstream supplying the creek. Fall conditions can also vary depending on rain events. These flow variations resulted in the temperature loggers being dewatered on numerous occasions, or possibly lost during high flows. There is also no measure as to exactly how much water is being released by the minimum flow structure. Winter temperatures at Site 4 consistently dropped below 2°C for the period on record which suggests this could be the natural, pre-disturbance conditions in the system. A more detailed study with loggers at identified spawning sites would be required to fully assess effects on Kokanee spawning and incubation. Before further study is undertaken, the challenges of changing bed profile and associated dewatering of loggers need to be addressed and flow gauging would be needed at the temperature logging locations. Due to the inconclusive evidence that increased flows would mitigate lower temperatures in Lower Cranberry Creek, a study needs to be conducted to test this assumption prior to fisheries effects monitoring. Therefore, the effect of increasing flow release on temperatures in Lower Cranberry Creek cannot be determined.

# 6.0 References

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Triton. 2012a. Walter Hardman Project Water Use Plan – Lower Cranberry Creek: Kokanee Spawning and Incubation Habitat Monitoring (WHNMON#1)

Triton. 2012b. Walter Hardman Project Water Use Plan – Lower Cranberry Creek: Rainbow Trout Rearing Habitat Monitoring (WHNMON#2)

# Appendix 1
# Quality Assurance Quality Control Table

| Site Description | 2007 | | | | 2008 | |
|---|---|---|---|---|---|---|
| | April 27, | | August 16, | | August, | |
| | Thermometer | Logger | Thermometer | Logger | Thermomete | Logger |
| Site 1, WHN 1 | 3.9 C | 4.18 C | 17.6 C | 17.6 C | 13 C | 12.82 C |
| Site 1, WHN 6 | 3.9 C | 4.19 C | 17.6 C | 19.02 C | 13 C | 12.84 C |
| Site 2, WHN 2 | 3.8 C | 3.9 C | 19.65 C | 21.15 C | 15.5 C | 15.47 C |
| Site 2, WHN 5 | 3.8 C | 3.91 | 19.65 C | 21.17 C | 15.5 C | 15.19 C |
| Site 3, WHN 3 | 4.2 C | N/A | N/A | N/A | N/A (found Dewa-tered) | N/A |
| Site 3, WHN 4 | 4.2 C | N/A | N/A | N/A | N/A | N/A |
| Site 4, 2295918 | Site 4 was not installed until Sept 2009 | | | | | |
| Site 4, 2295737 | | | | | | |

| Site Description | 2008 | | 2009 | | 2010 | |
|---|---|---|---|---|---|---|
| | October 27, | | June 8, | | May 7, | |
| | Thermometer | Logger | Thermometer | Logger | Thermomet | Logger |
| Site 1, WHN 1 | N/A | 1.83 C | 6.65 C | 7.07 C | 5.5 C | 5.77 C |
| Site 1, WHN 6 | N/A | 1.25 C | 6.65 C | 9.11 C | 5.5 C would not connect | |
| Site 2, WHN 2 | N/A | 2.42 C | N/A | 9.97 C | 8.0 C | |
| Site 2, WHN 5 | N/A | 2.44 C | No Data | | 8.0 C | 7.19 C |
| Site 3, WHN 3 | N/A | N/A | No Data | | N/A | N/A |
| Site 3, WHN 4 | N/A | N/A | N/A WHN 4 Found out of water | 21.7 | N/A | N/A |
| Site 4, 2295918 | | | | | 5 C | 2.74 C |
| Site 4, 2295737 | | | | | 5 C | 2.77 C |

| Site Description | 2010 | | | | 2011 | |
|---|---|---|---|---|---|---|
| | July 28, | | November 17, | | May 4, | |
| | Thermometer | Logger | Thermometer | Logger | Thermometer | Logger |
| Site 1, WHN 1 | N/A | 12.39 C | Lost all data for all sites until May 2011 | | 4 C | N/A |
| Site 1, WHN 6 | N/A | 19.98 C | | | 4 C | 4.42 C |
| Site 2, WHN 2 | N/A | | | | 4 C | 3.17 C |
| Site 2, WHN 5 | N/A | 9.61 C | | | 4 C | 5.23 C |
| Site 3, WHN 3 | N/A | 13.35 C | | | 5 C | 5.77 C |
| Site 3, WHN 4 | N/A | 13.25 C | | | 5 C | 5.36 C |
| Site 4, 2295918 | N/A | 12.72 C | | | 3 C | 3.2 C |
| Site 4, 2295737 | N/A | 12.72 C | | | 3 C | 3.17 C |

| Site Description | 201 | | 2012 | |
|---|---|---|---|---|
| | September 2, | | September 18, | |
| | Thermometer | Logger | Thermomete | Logger |
| Site 1, WHN 1 | 11 C | N/A | 10 C | 10.02 C |
| Site 1, WHN 6 | 11 C | 11.66 C | 10 C | N/A |
| Site 2, WHN 2 | 12 C | 8.47 C | 9.5 C | 9.14 C |
| Site 2, WHN 5 | 12 C | N/A | 9.5 C | 10.2 C |
| Site 3, WHN 3 | 13 C | 14.21 C | 10 C | 7.42 C |
| Site 3, WHN 4 | 13 C | N/A | 10 C | 9.29 C |
| Site 4, 2295918 | 8 C | 9.61 C | 7 C | 7.94 C |
| Site 4, 2295737 | 8 C | 9.26 C | 7 C | N/A |

# Appendix 2
# Water Temperature Data Figures

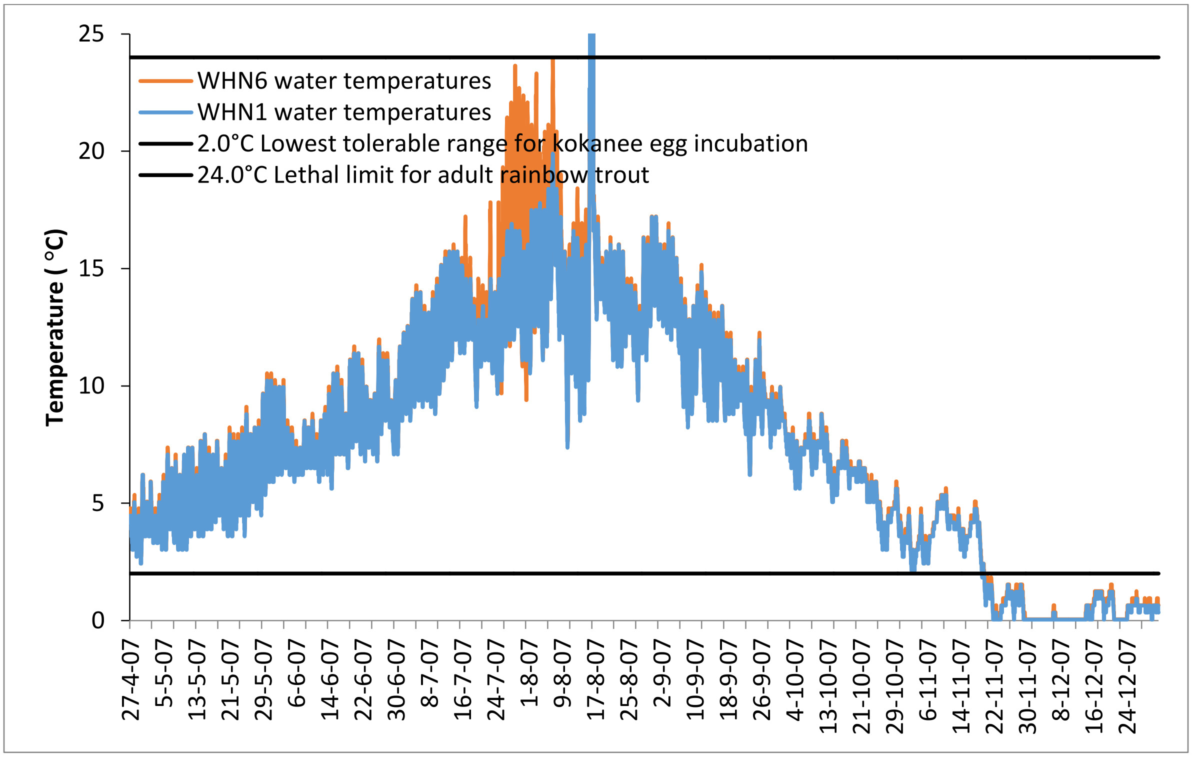


**Figure 1.** Water temperatures recorded from April to December 2007 at Site 1 from both WHN1 and WHN6 temperature loggers.

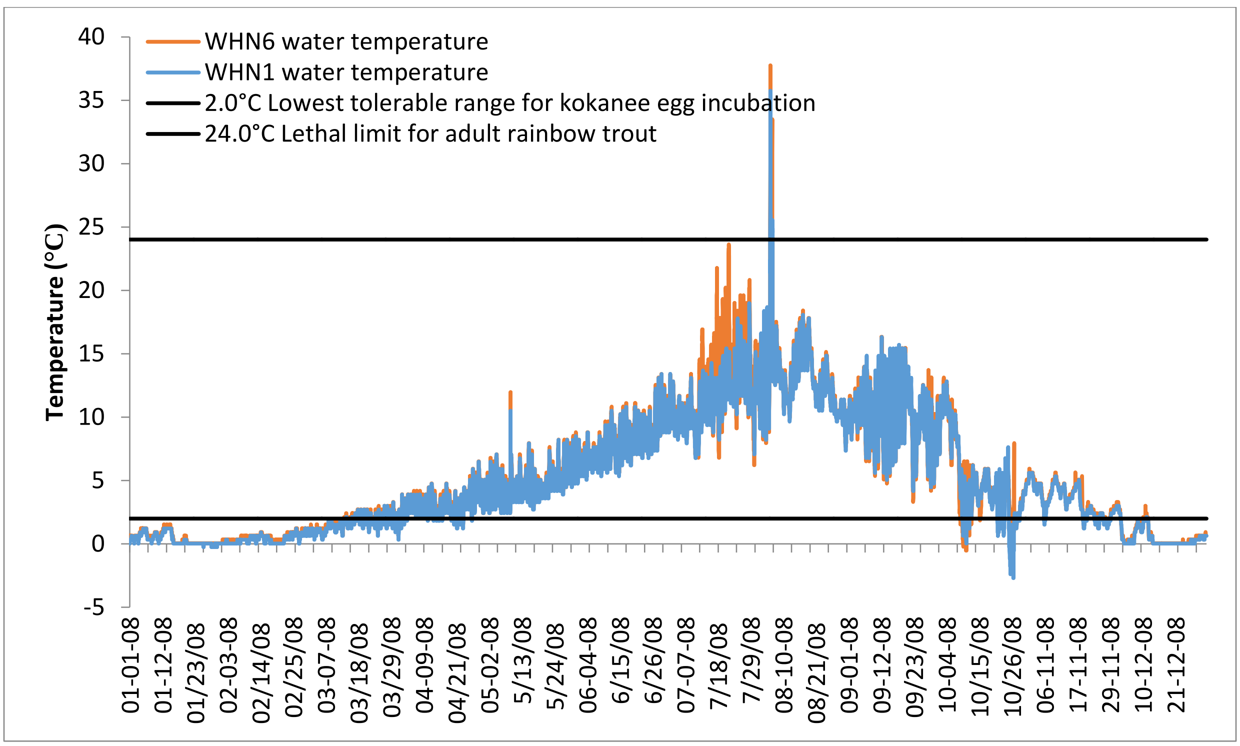


**Figure 2.** Water temperatures recorded from January to December 2008 at Site 1 from both WHN1 and WHN6 temperature loggers.

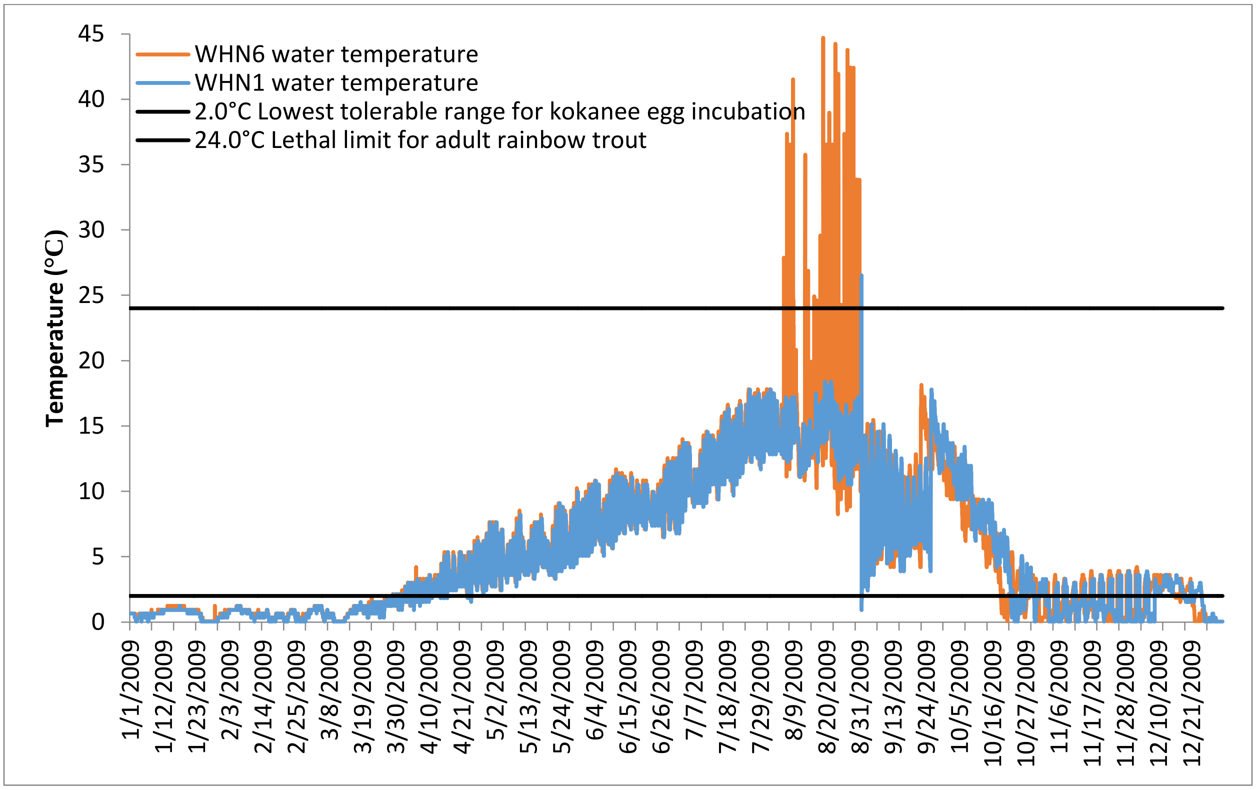


**Figure 3.** Water temperatures recorded from January to December 2009 at Site 1 from both WHN1 and WHN6 temperature loggers.

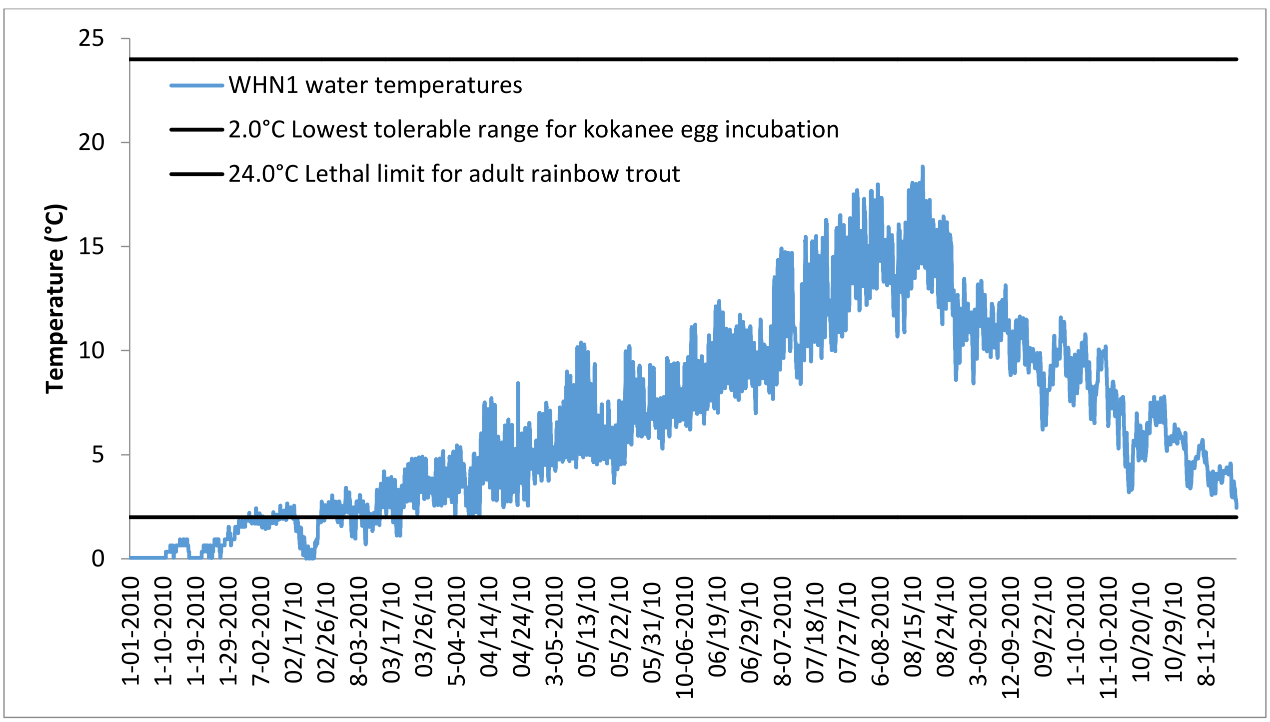


**Figure 4**. Water temperatures recorded from January to November 2010 at Site 1 from the WHN1 temperature logger.

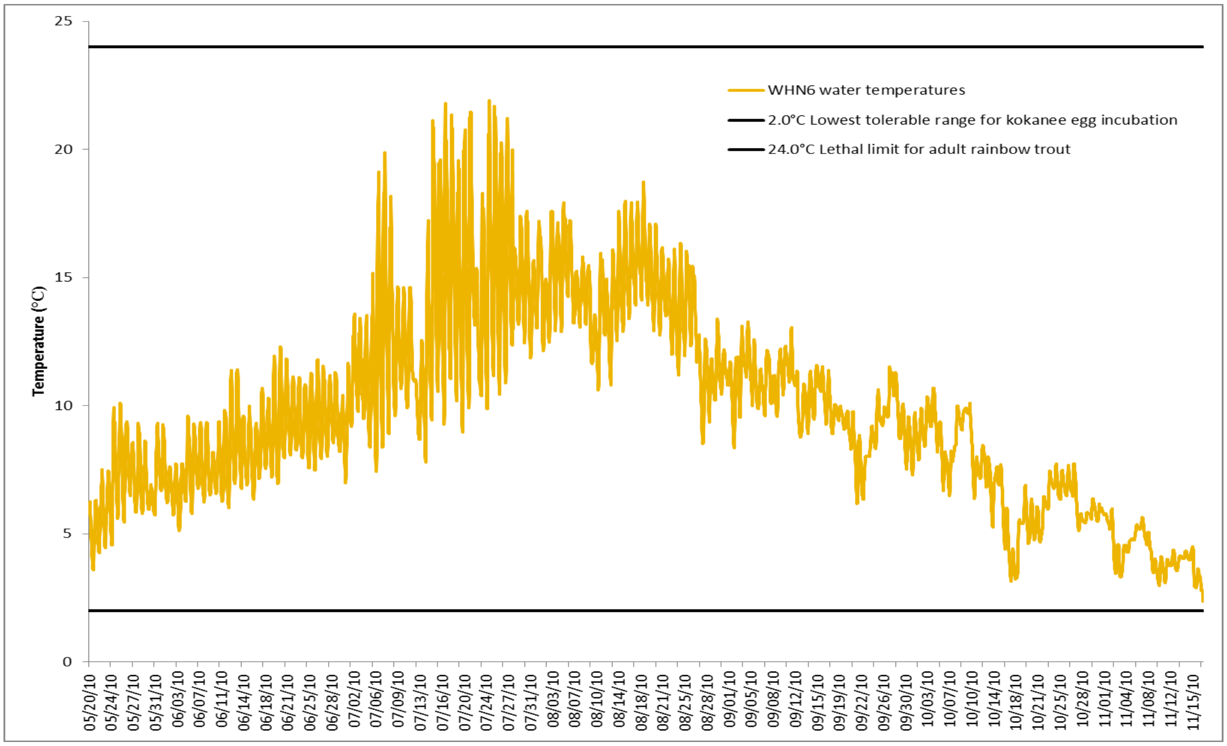


**Figure 5.** Water temperatures recorded from May to November 2010 at Site 1 from the WHN6 temperature logger.

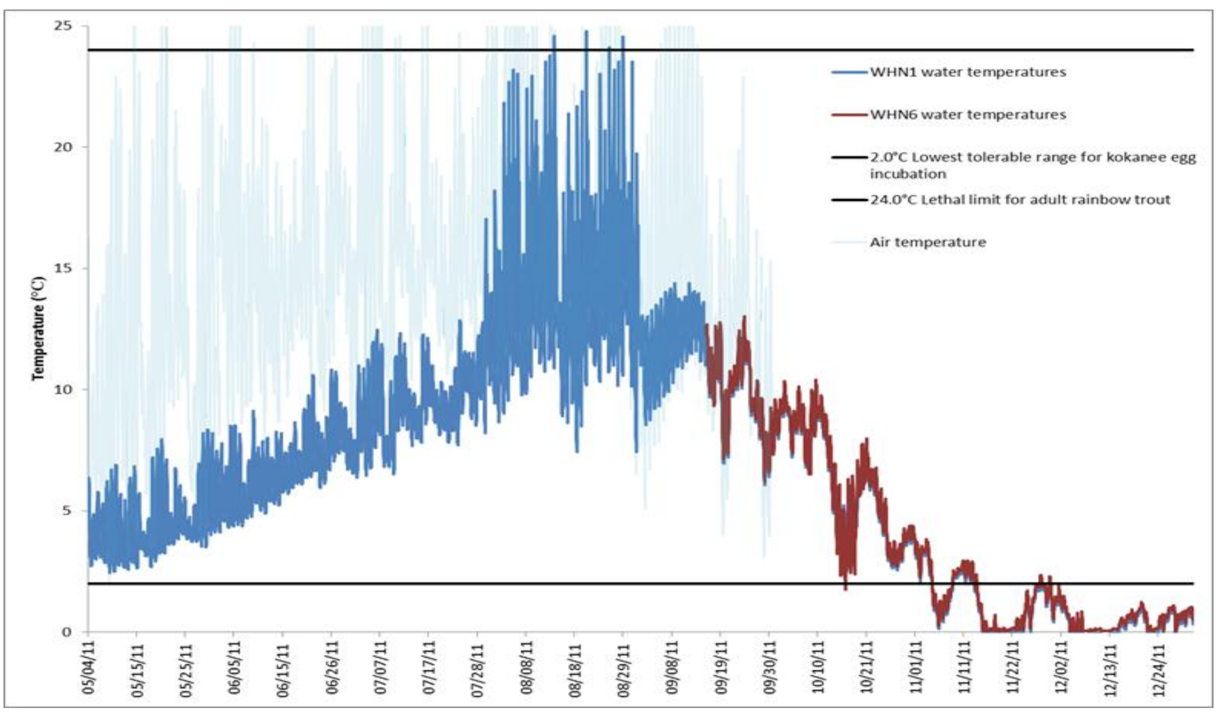


**Figure 6.** Water and air temperatures recorded from May to December 2011 at Site 1 from the WHN1 temperature logger, and September to December 2011 from the WHN6 temperature logger.

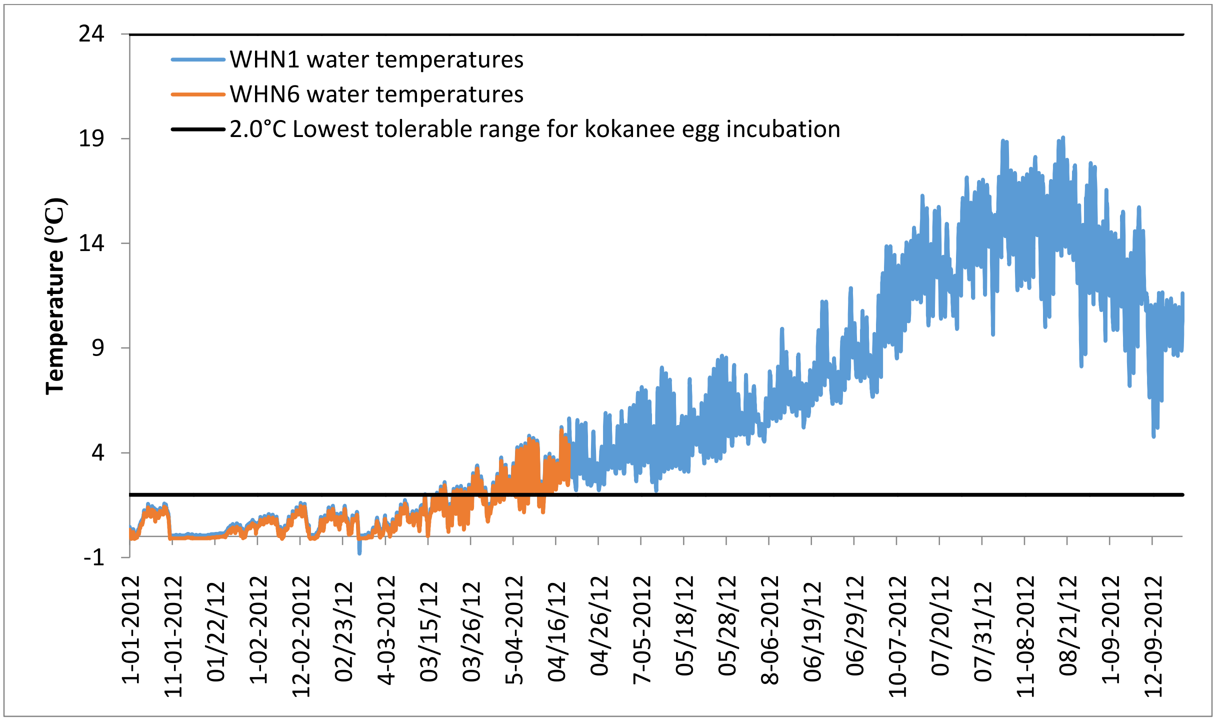


**Figure 7**. Water temperatures recorded from January to April 2012 at Site 1 from the WHN6 temperature logger, and January to September 2012 from the WHN1 temperature logger. September 2012 marks the final monitoring month for the project.

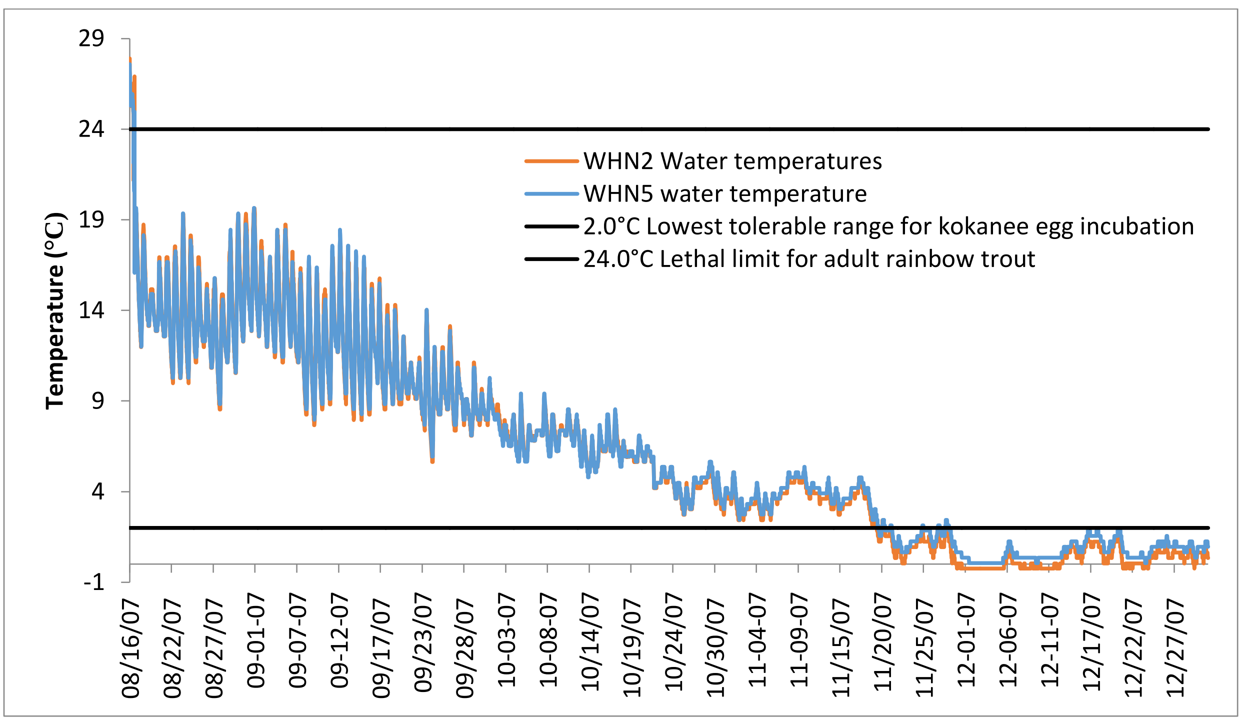


**Figure 8.** Water temperatures recorded from August to December 2007 at Site 2 from both WHN2 and WHN5 temperature loggers.

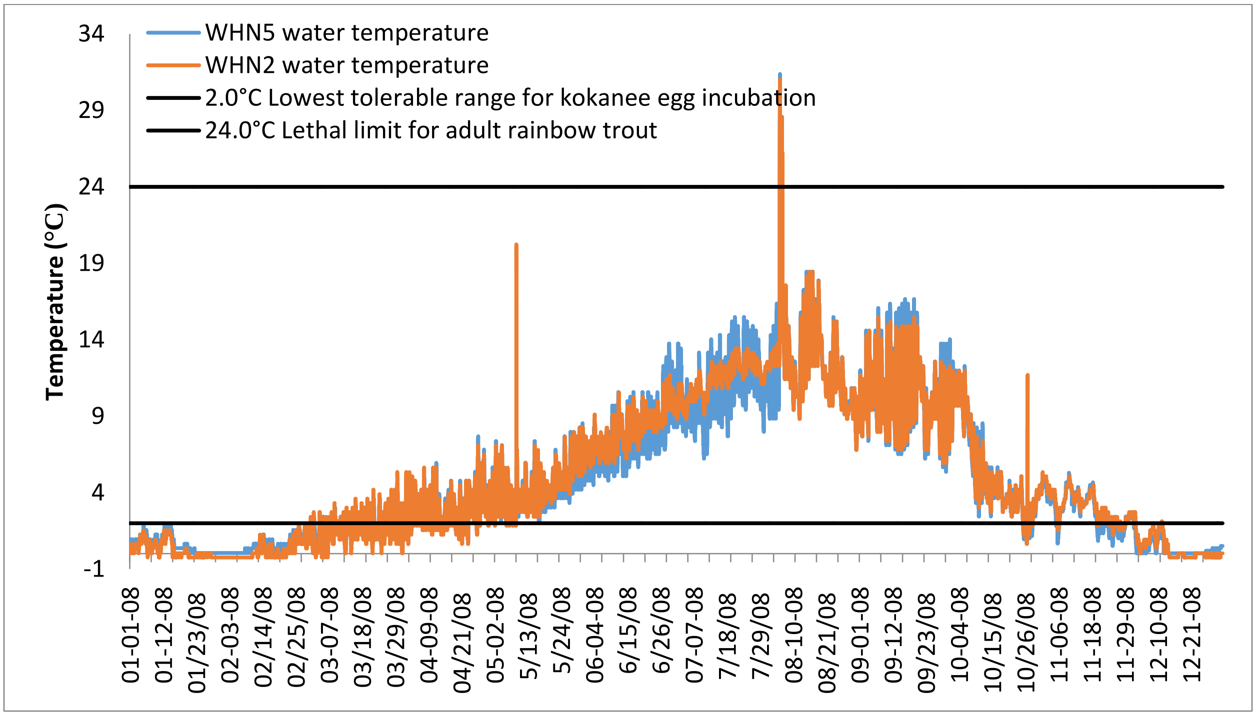


**Figure 9**. Water temperatures recorded from January to December 2008 at Site 2 from both WHN2 and WHN5 temperature loggers.

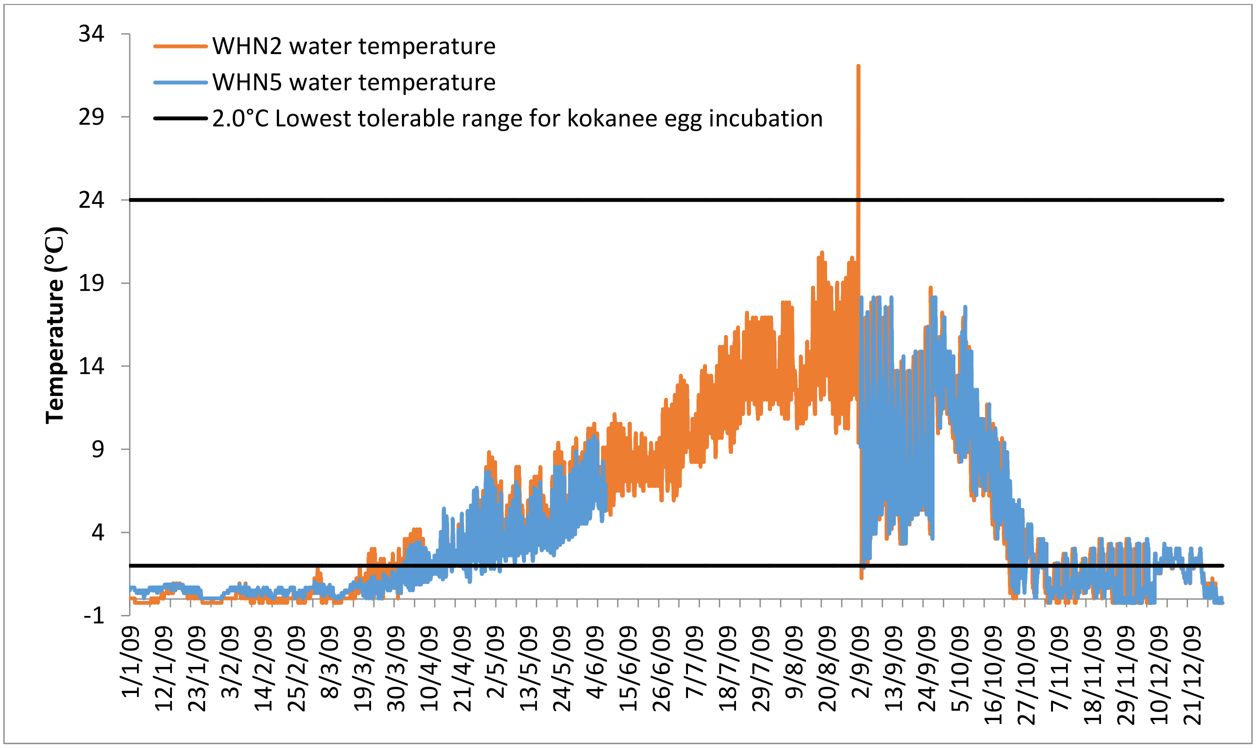


**Figure 10.** Water temperatures recorded from January to December 2009 at Site 2 from the WHN2 temperature logger, and January to June, and September to December 2009 from the WHN5 temperature logger.

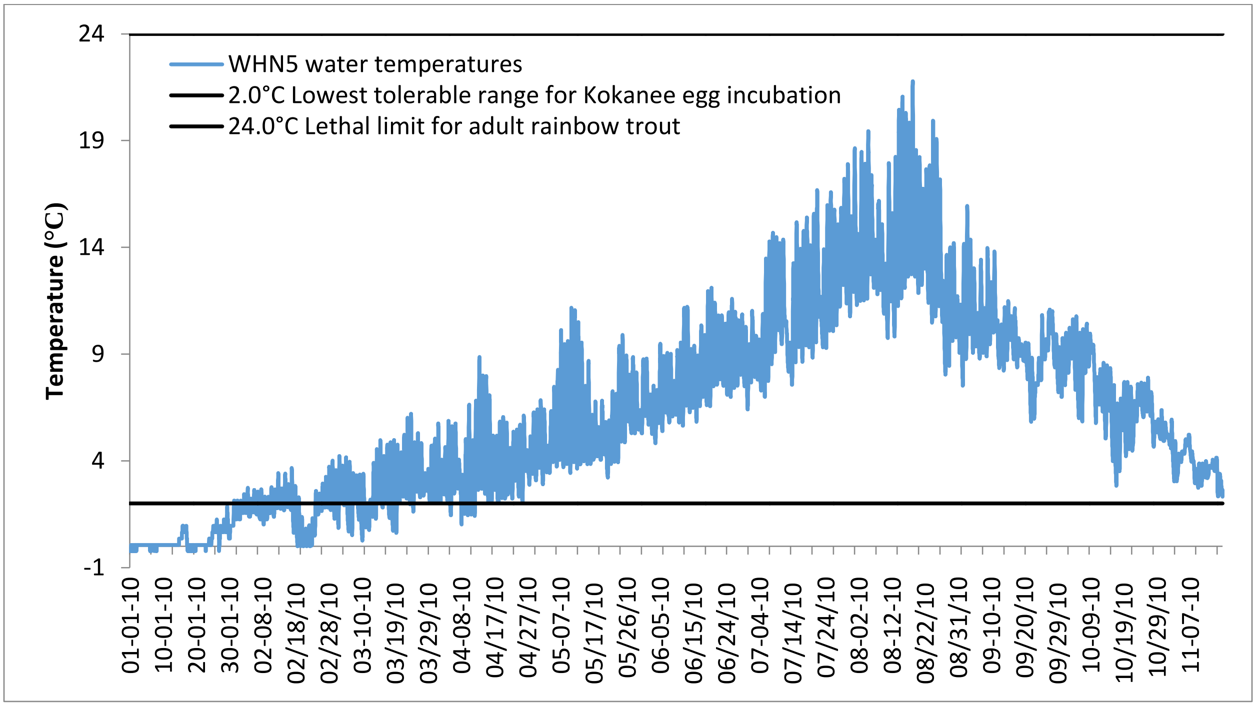


**Figure 11**. Water temperatures recorded from January to November 2010 at Site 2 from the WHN5 temperature logger.

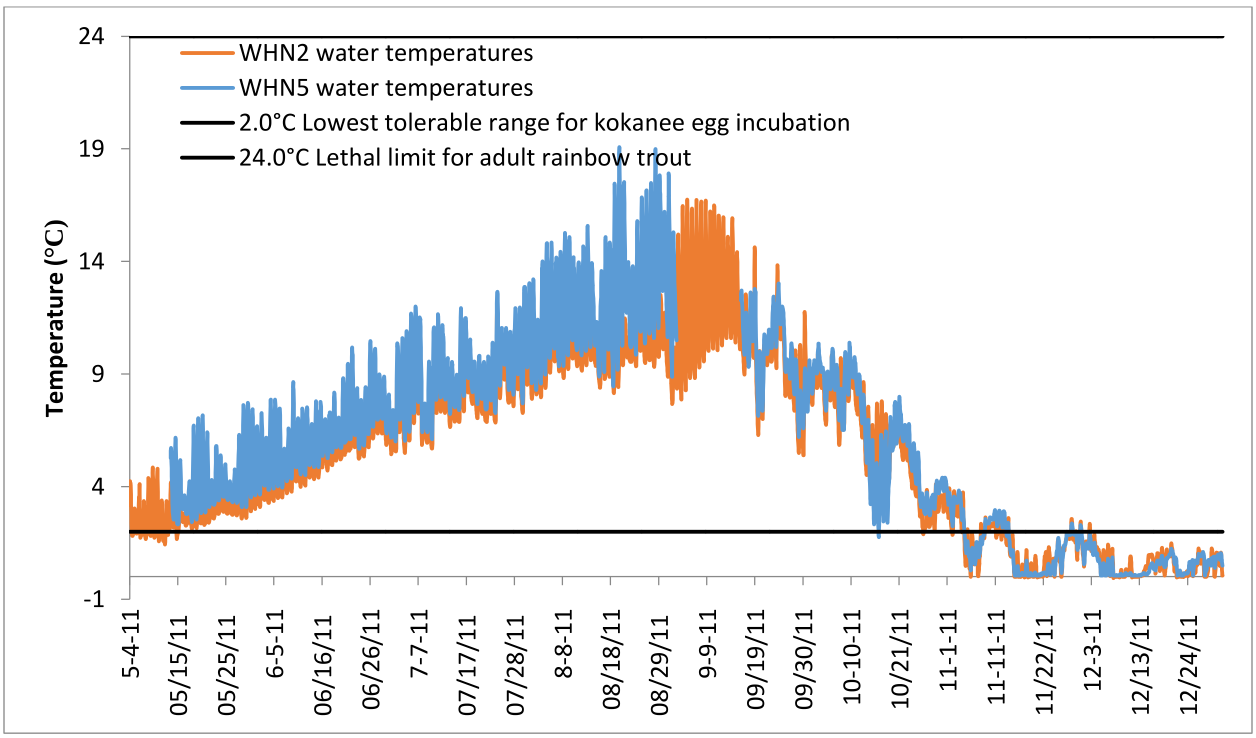


**Figure 12.** Water temperatures recorded from May to December 2011 at Site 2 from the WHN2 temperature logger, and May to August, and September to December 2011 from the WHN5 temperature logger.

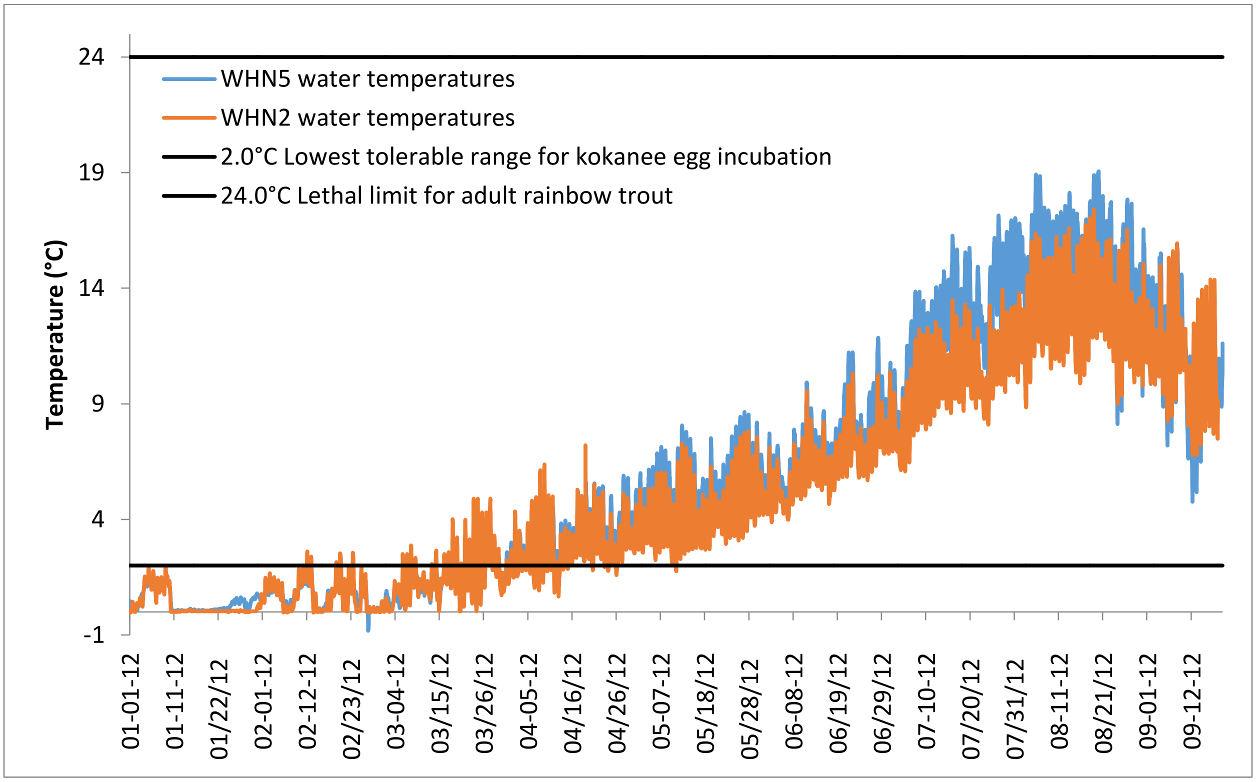


**Figure 13.** Water temperatures recorded from January to September 2012 at Site 2 from both WHN2 and WHN5 temperature loggers.

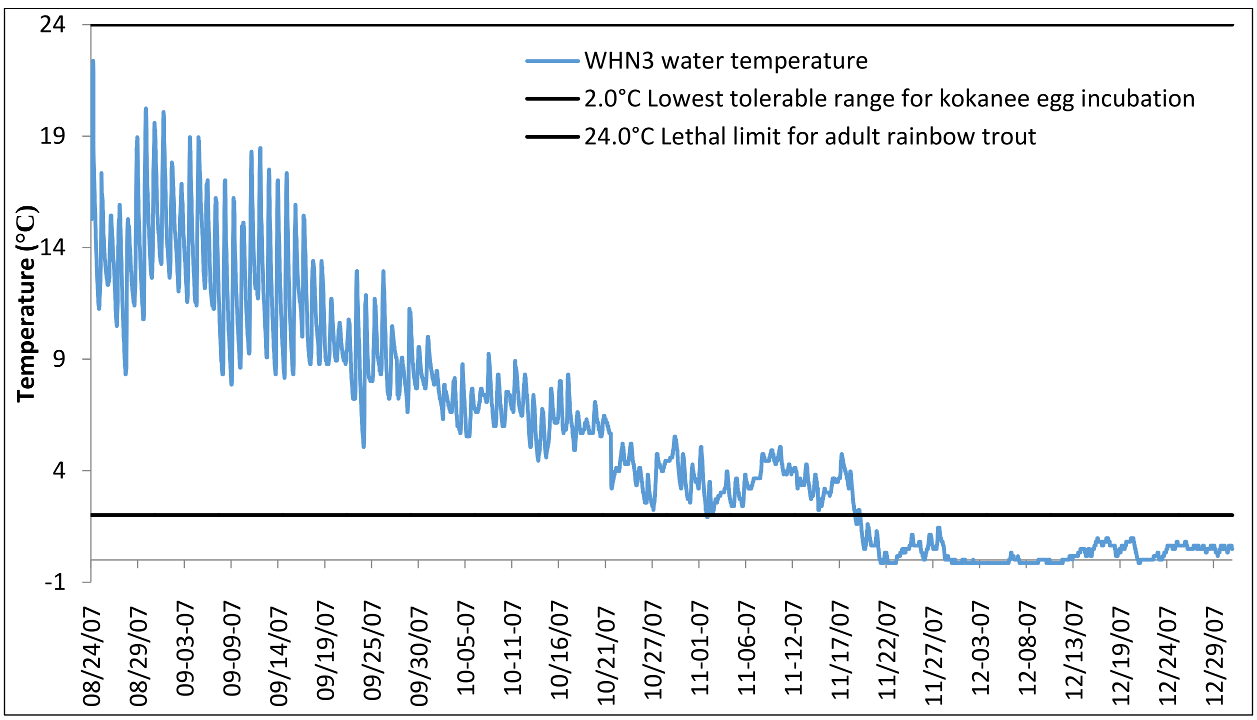


**Figure 14.** Water temperatures recorded from August to December 2007 at Site 3 from the WHN3 temperature logger. Data from the WHN4 temperature logger is not available.

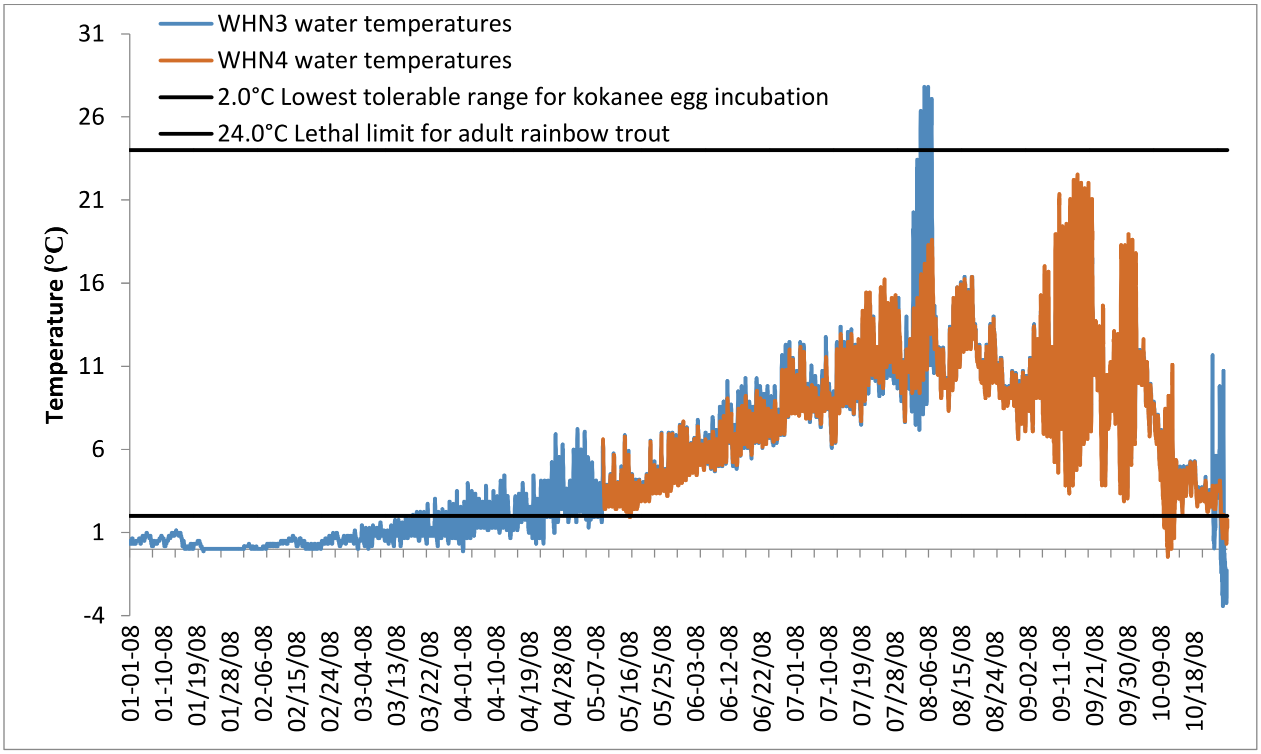


**Figure 15.** Water temperatures recorded from January to October 2008 at Site 3 from the WHN3 temperature logger, and May to October for the WHN4 temperature logger.

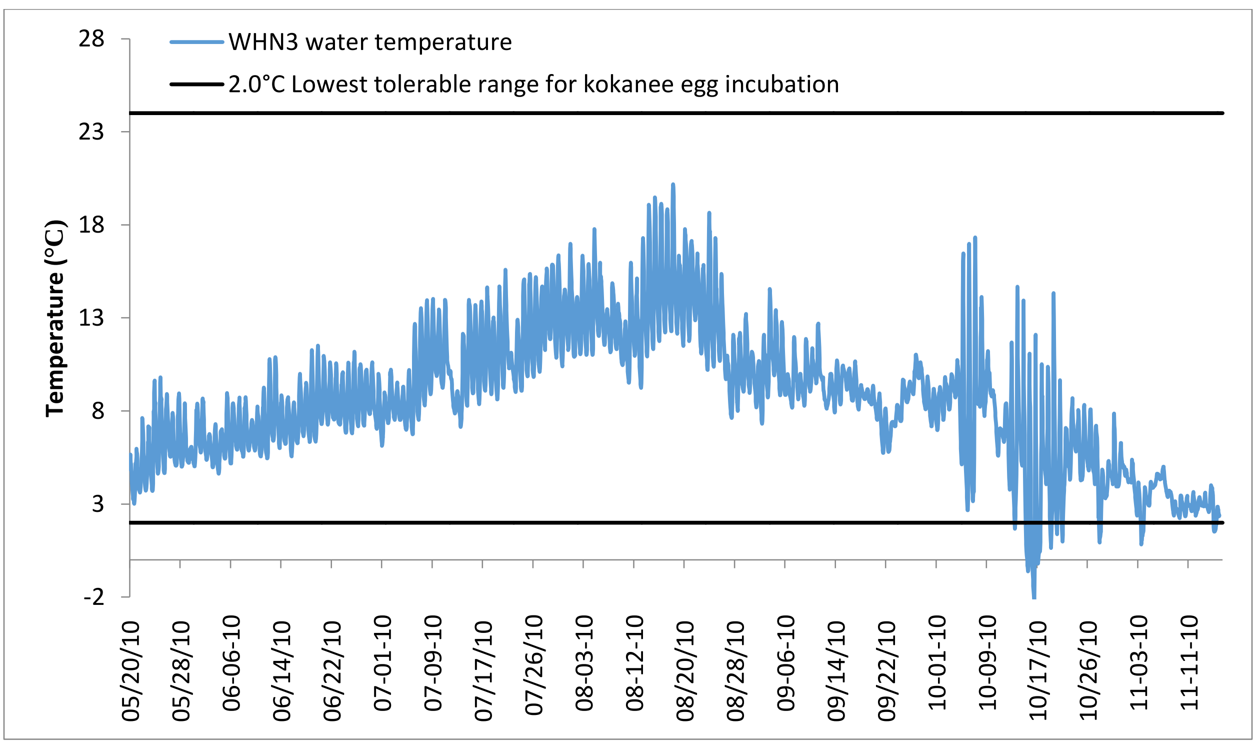


**Figure 16.** Water temperatures recorded from May to November 2010 at Site 3 from the WHN3 temperature logger. Data measured at 60 minute intervals.

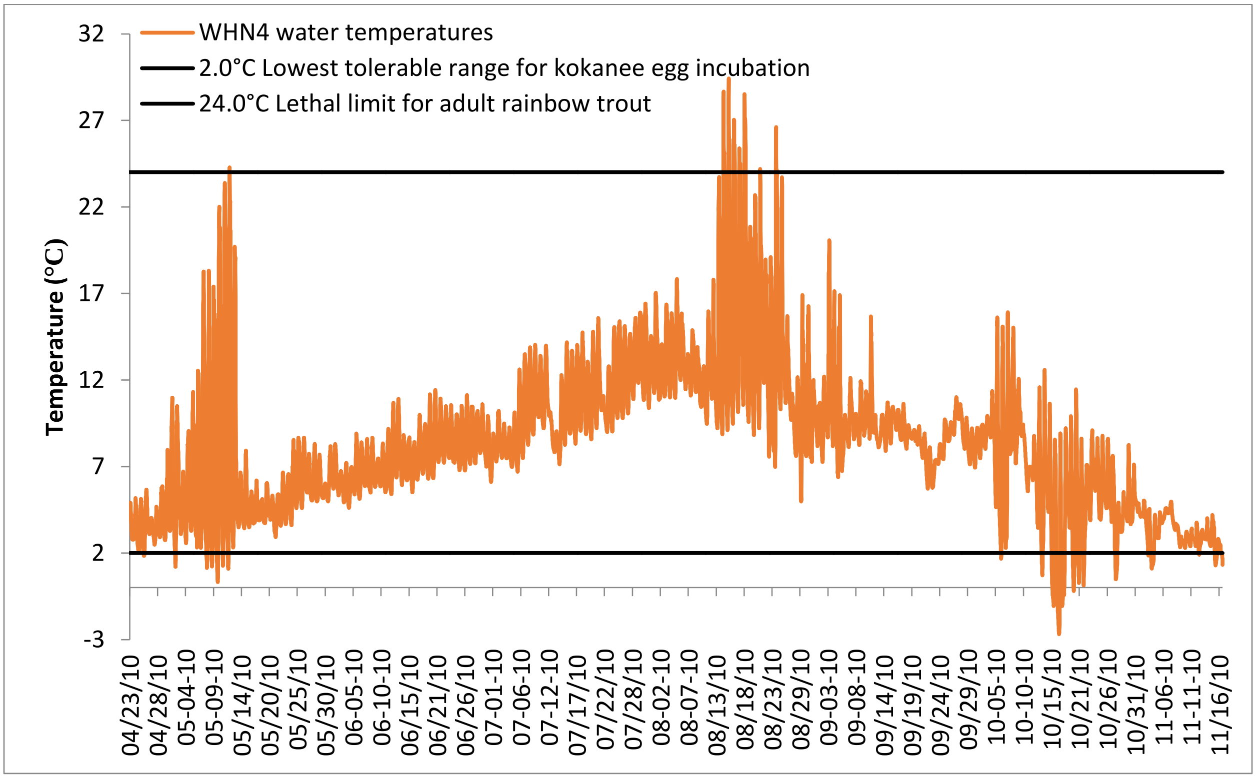


**Figure 17.** Water temperatures recorded from April to November 2010 at Site 3 from the WHN4 temperature logger. Data measured at 30 minute intervals.

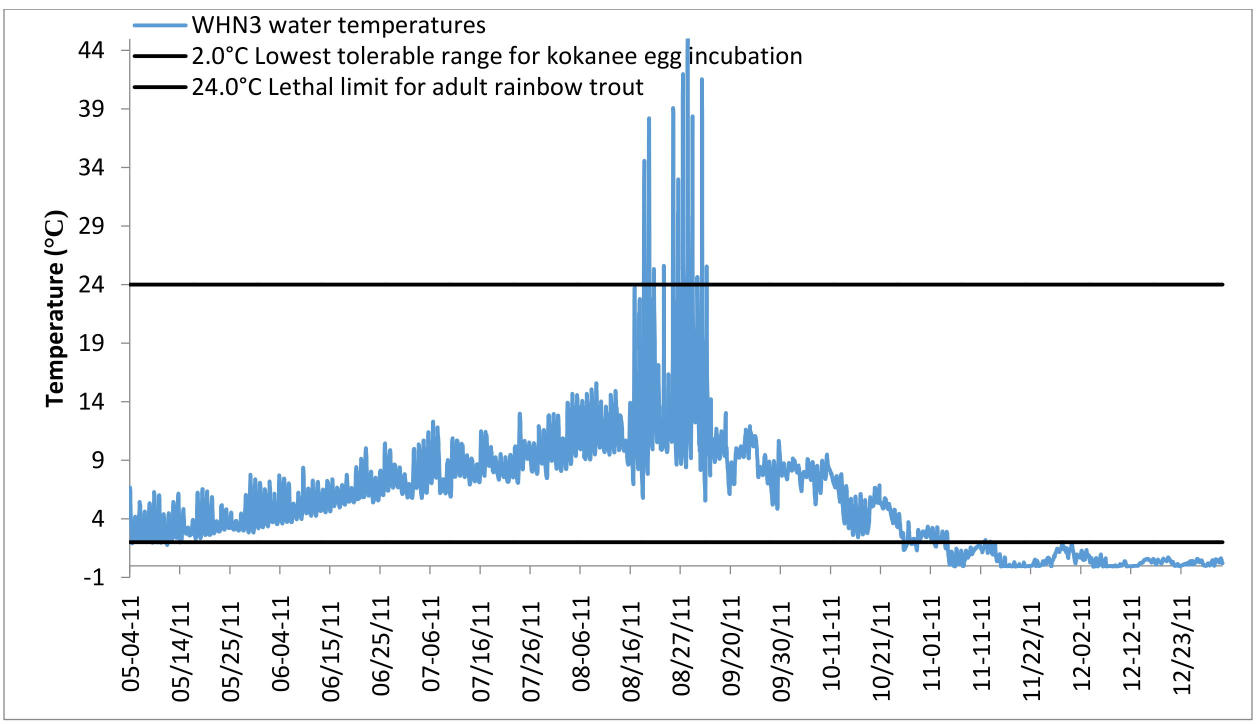


**Figure 18**. Water temperatures recorded from May to December 2011 at Site 3 from the WHN3 temperature logger. Data measured at 60 minute intervals.

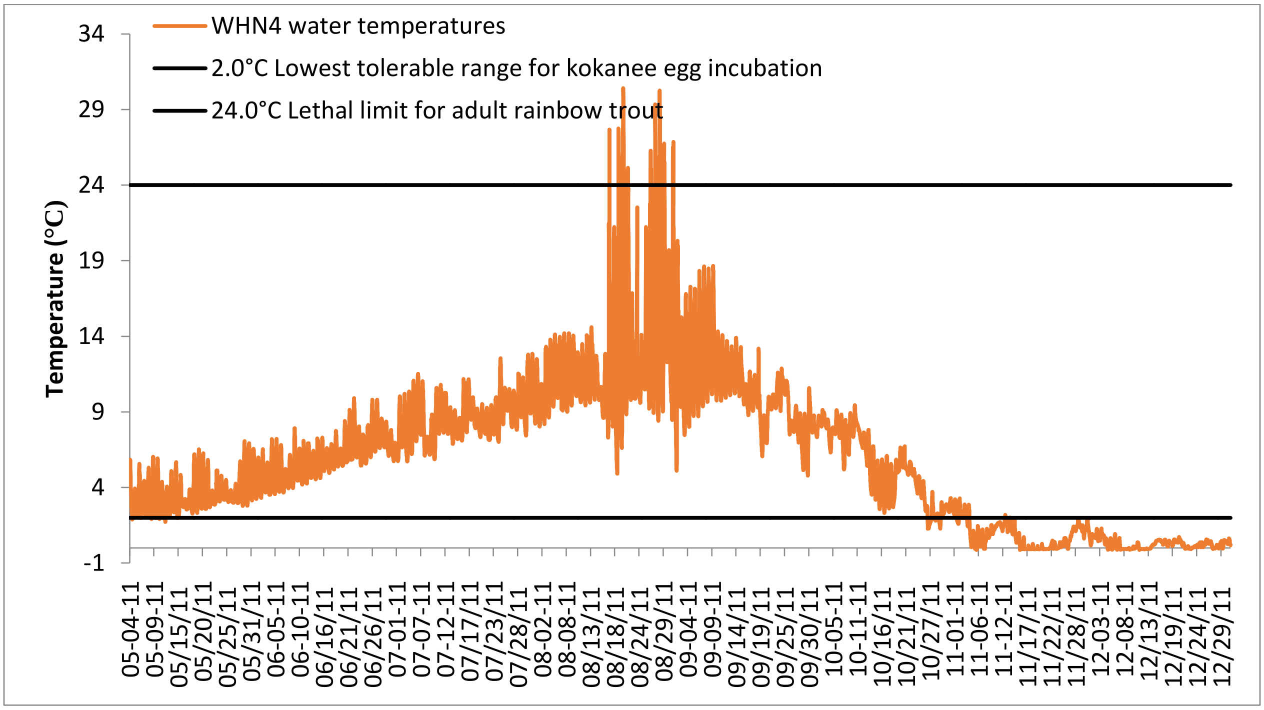


**Figure 19.** Water temperatures recorded from May to December 2011 at Site 3 from the WHN4 temperature logger. Data measured at 30 minute intervals.

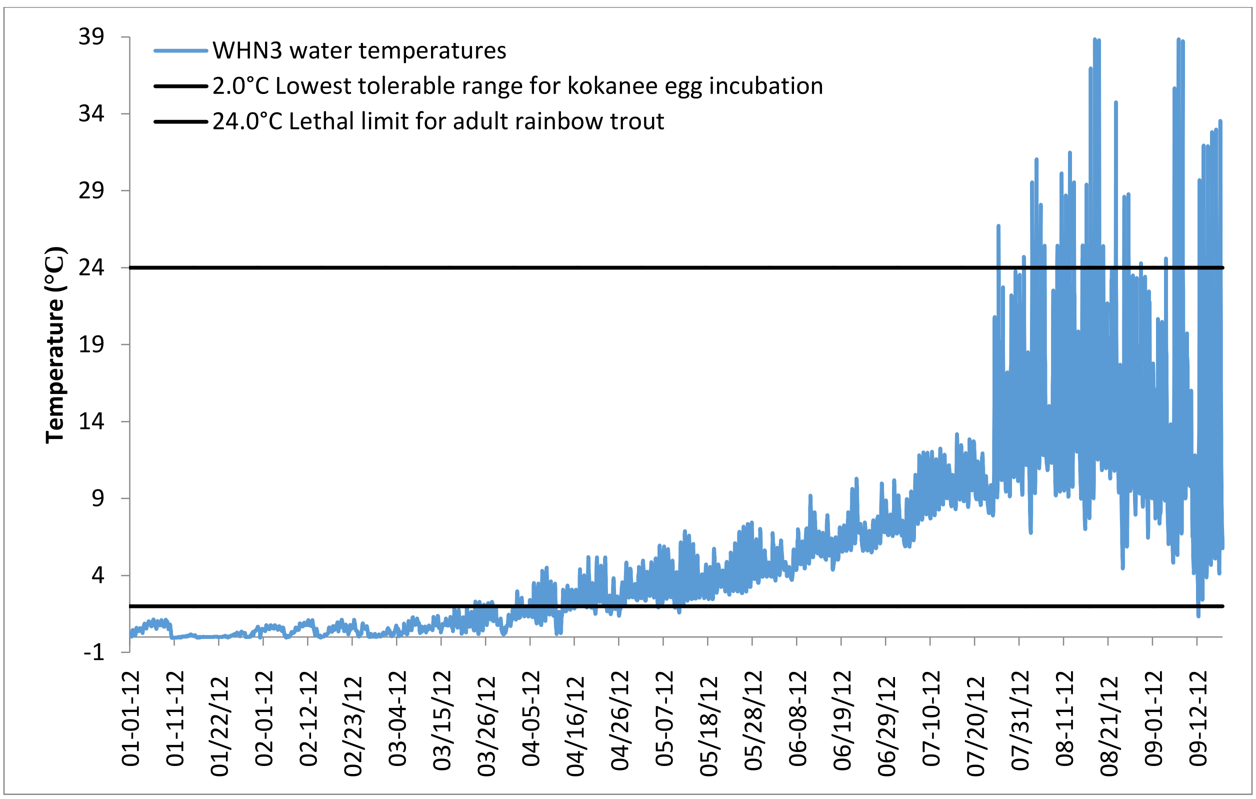


**Figure 20.** Water temperatures recorded from January to September 2012 at Site 3 from the WHN3 temperature logger. Data measured at 60 minute intervals.

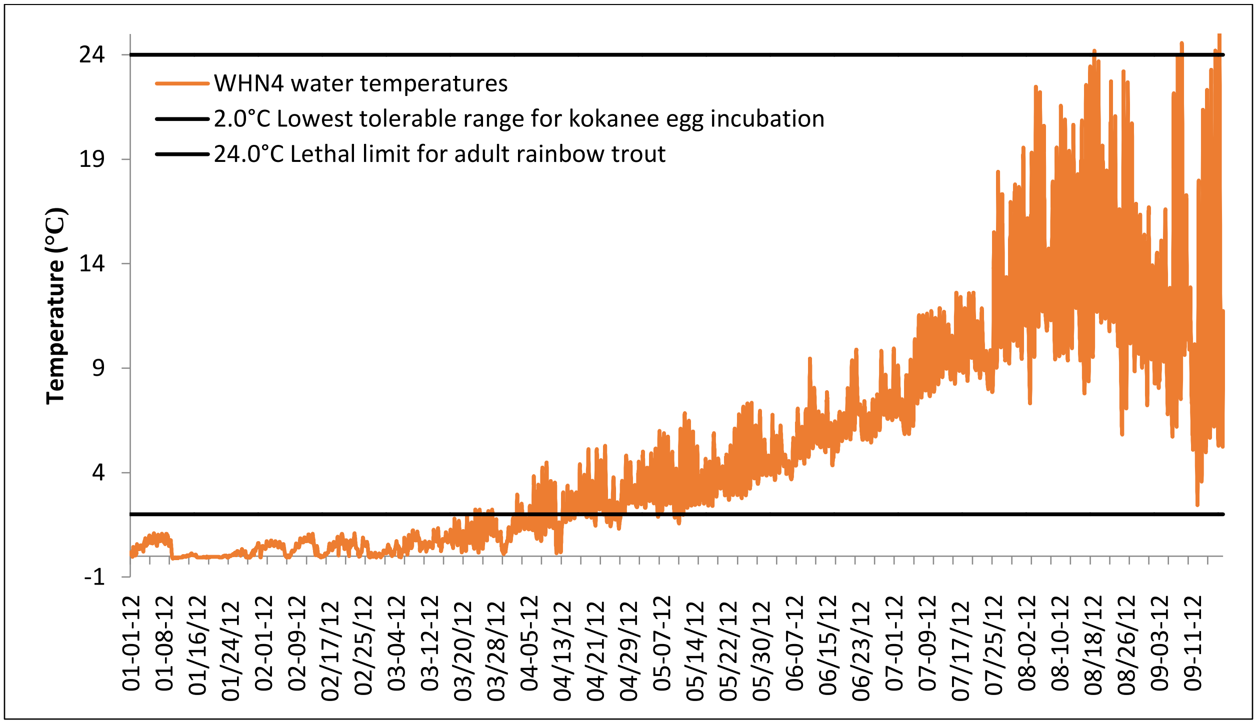


**Figure 21**. Water temperatures recorded from January to September 2012 at Site 3 from the WHN4 temperature logger. Data measured at 30 minute intervals.

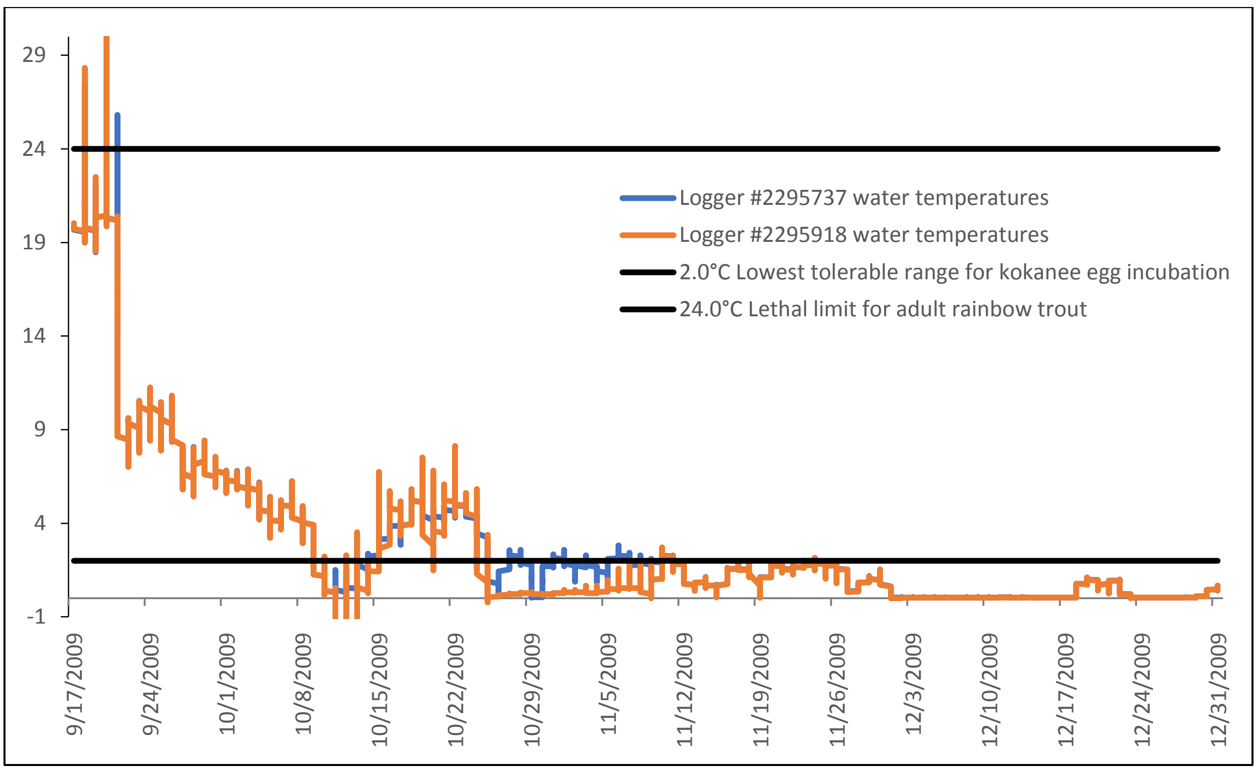


**Figure 22.** Water temperatures recorded from September to December 2009 at Site 4 (control) from logger #2295737, and logger #2295918.

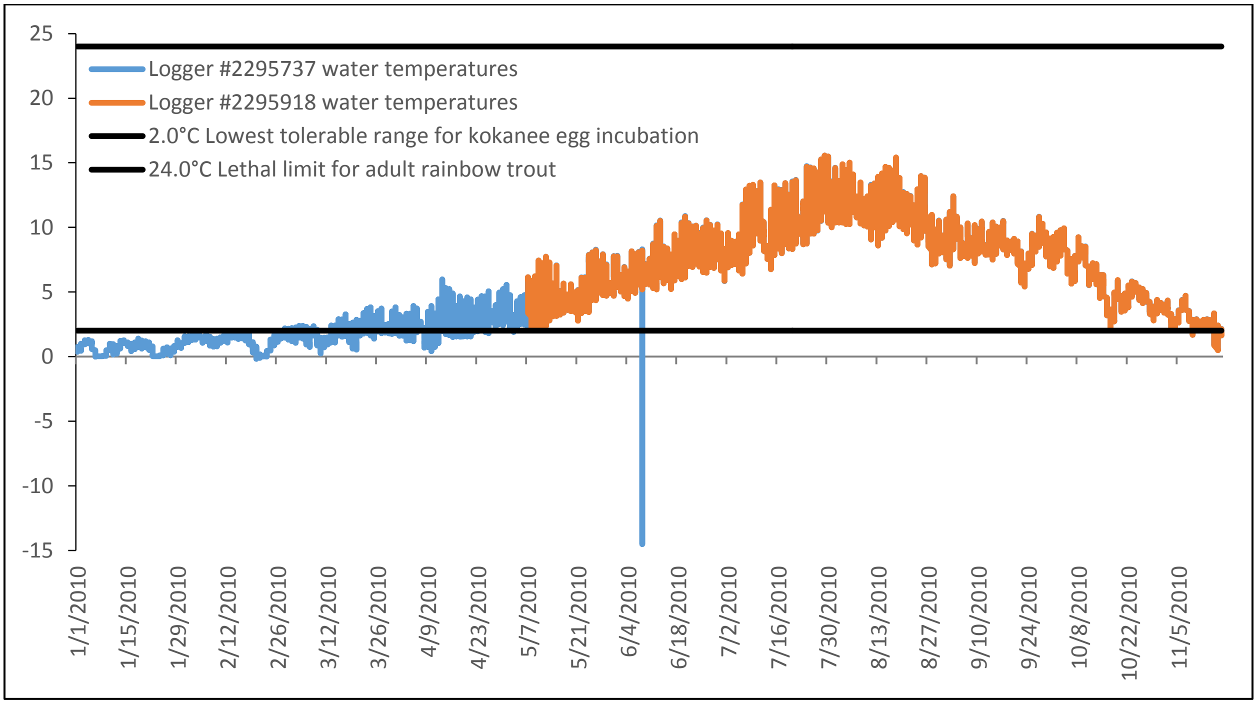


**Figure 23.** Water temperatures recorded from January to November 2010 at Site 4 (control) from logger #2295737, and logger #2295918.

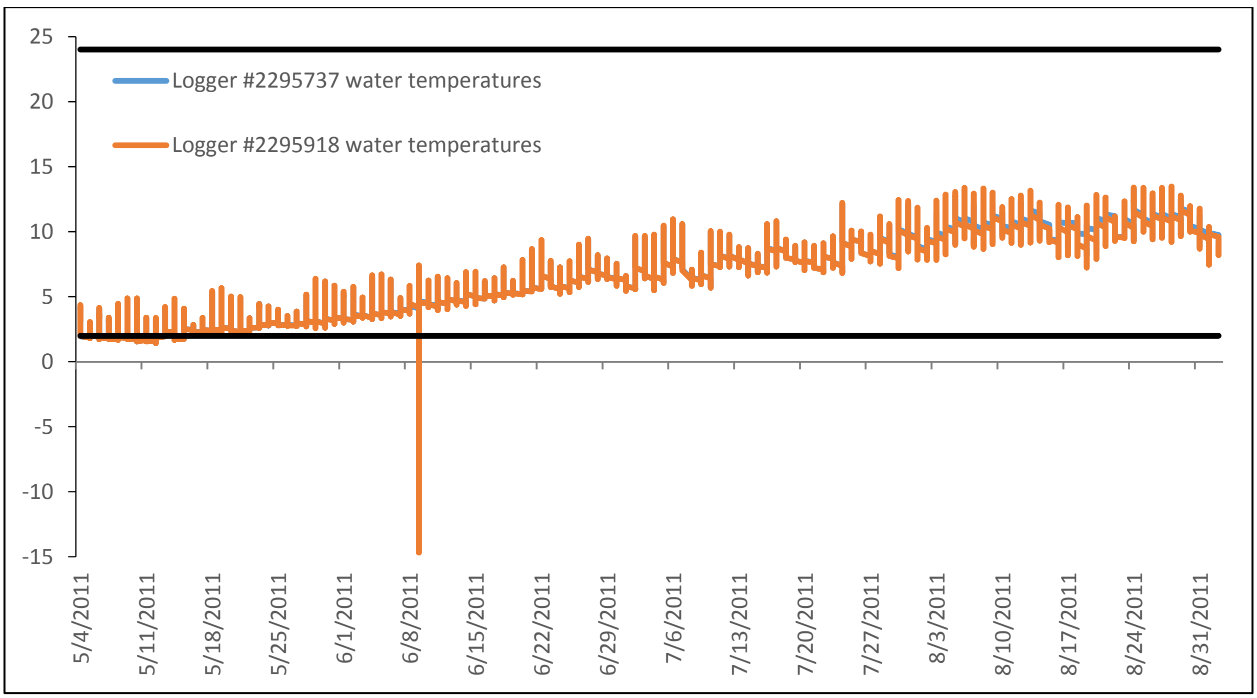


**Figure 24.** Water temperatures recorded from May to August 2011 at Site 4 (control) from logger #2295737, and logger #2295918.

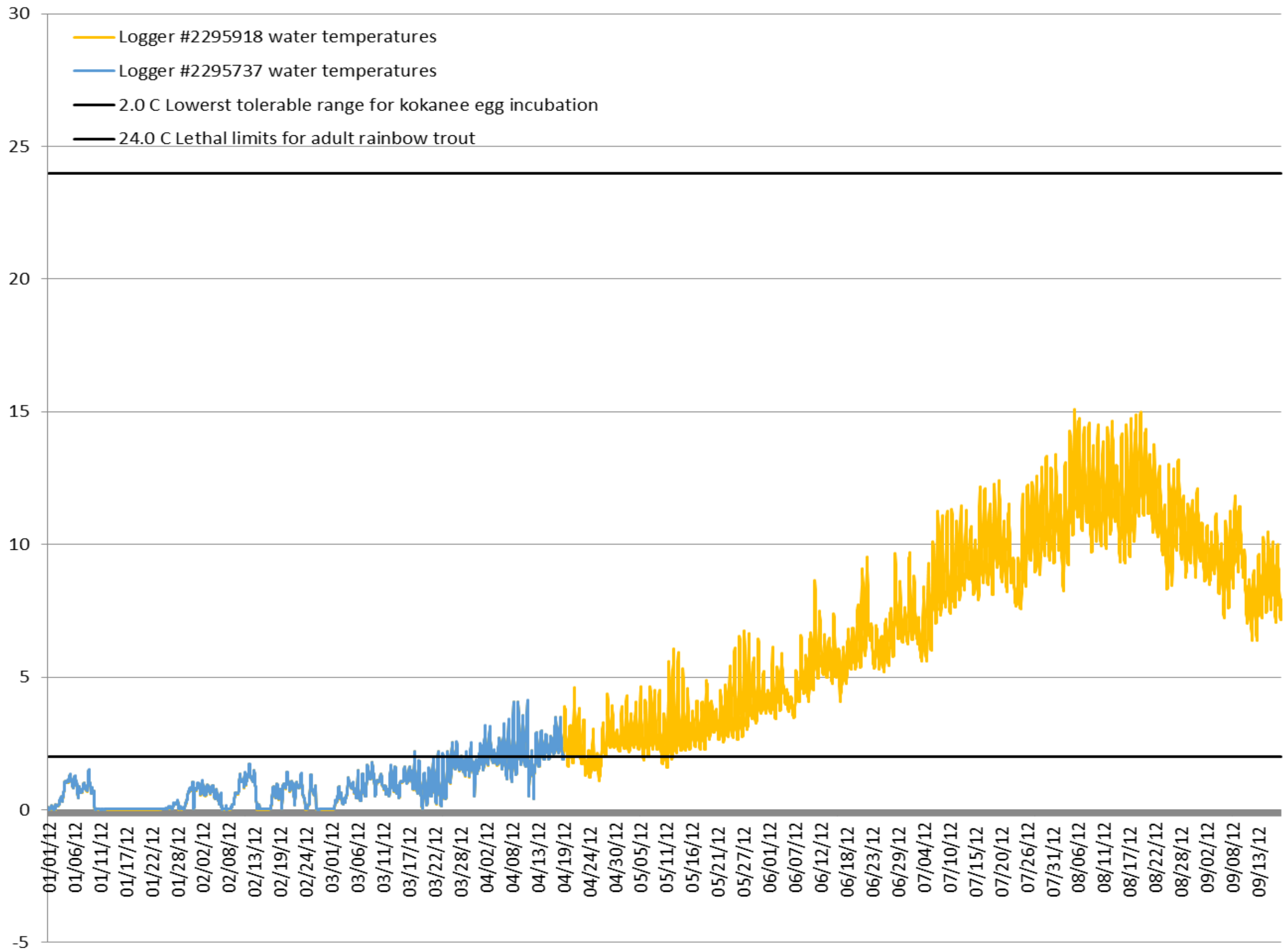


**Figure 25.** Water temperatures recorded from January to September 2012 at Site 4 (control) from logger #2295737, and logger #2295918.

# Appendix 3
# Discharge Figures

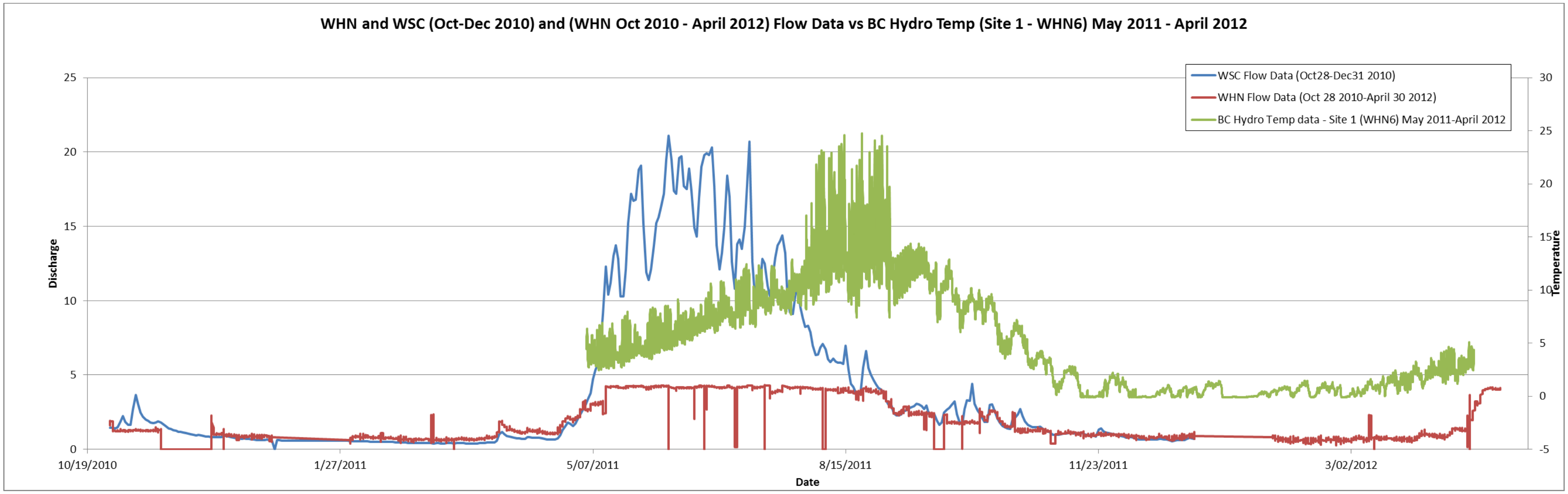


**Figure 1.** WHN and WSC (October to December 2010) and WHN (October 2010 to April 2012) flow data vs. BC Hydro temperature (Site 1 – WHN6) May 2011 to April 2012

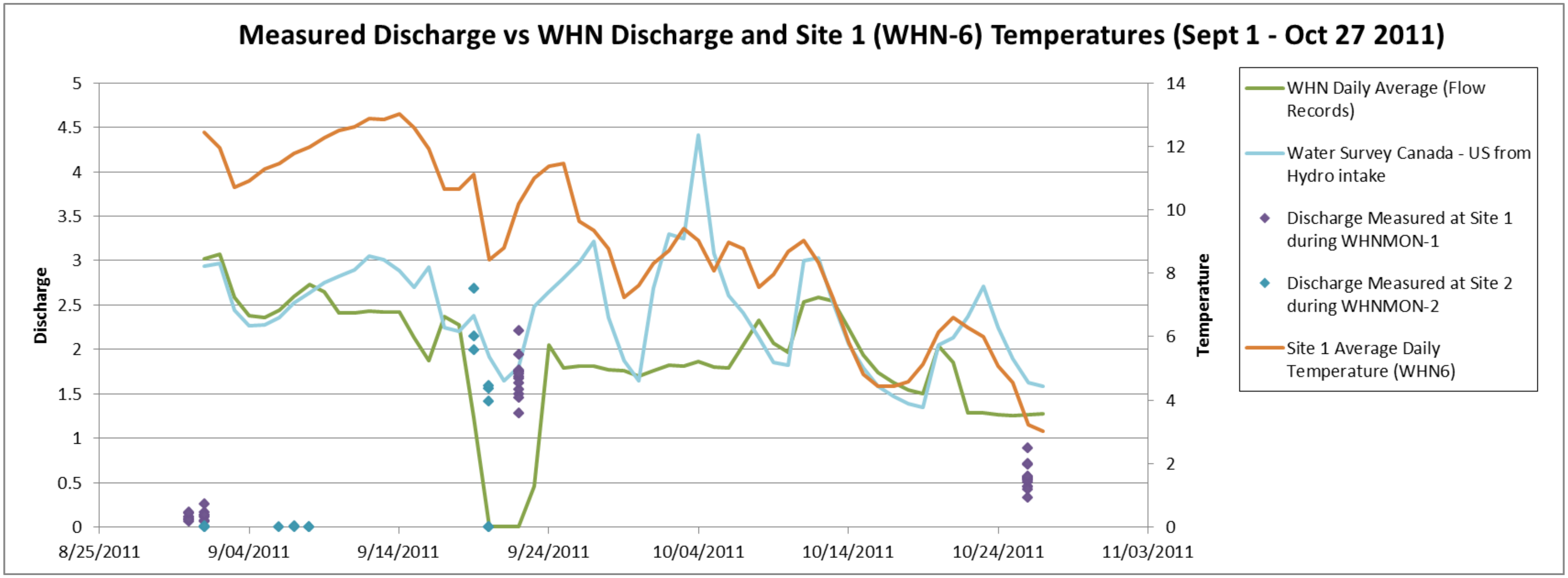


**Figure 2.** Measured discharge vs. WHN discharge and Site 1 (WHN6) temperatures September 1 to October 27, 2011

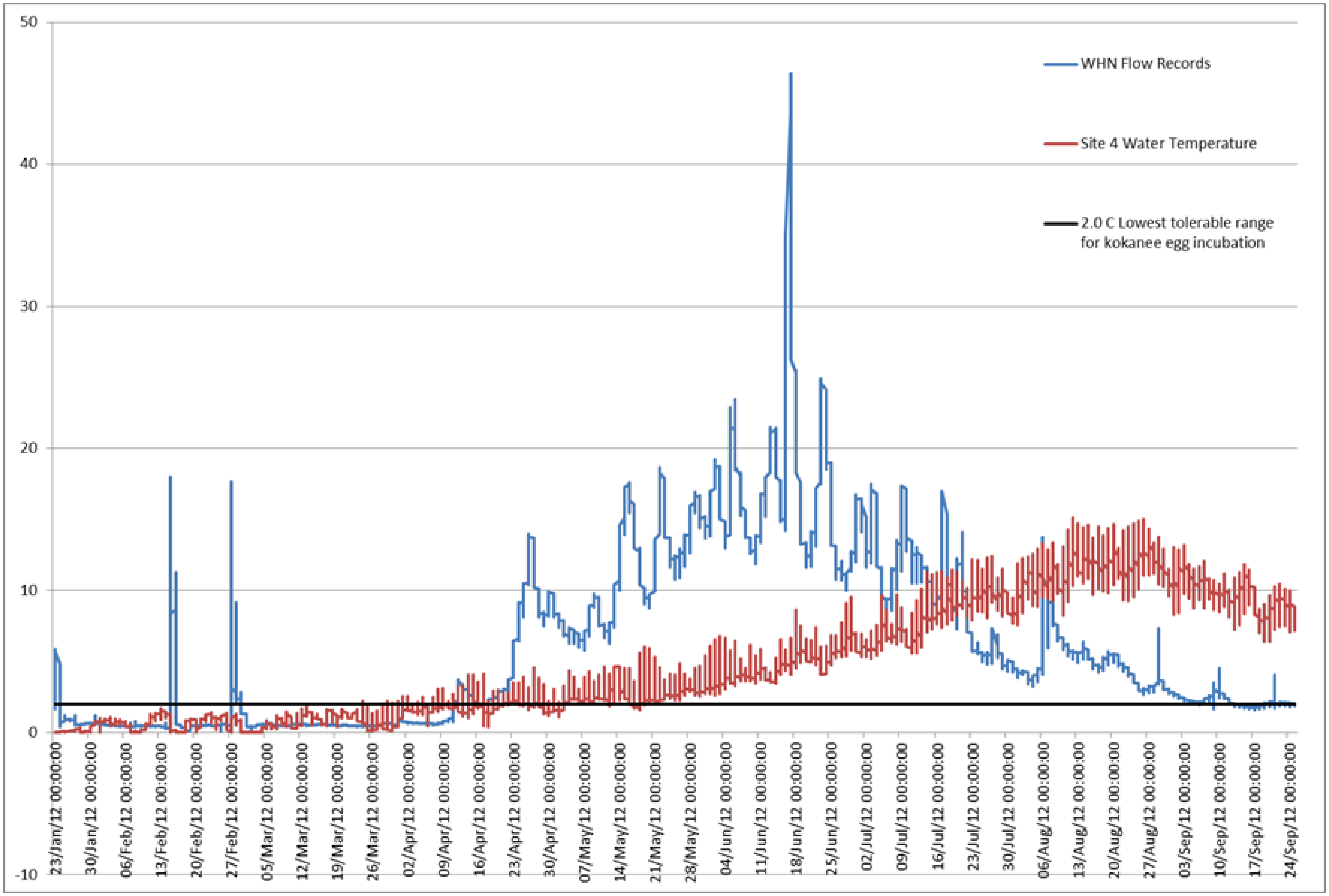


**Figure 3.** WHN discharge and Site 4 temperatures January 1, 2012 to September 18, 2012