

# **2011 Lower Granite Fish Ladder and Forebay Temperature Data Analysis**

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January 2012

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## 1.0 INTRODUCTION

Differential water temperatures in the adult fish ladder at Lower Granite Dam have been an area of concern for several years. Water in the upper reaches of the ladder is warmer relative to water in the mid and lower reaches. These thermal differences can potentially have a negative impact on adult salmon migration.

The Walla Walla District office (NWW) of the U.S. Army Corps of Engineers (USACE) is evaluating several alternatives that are intended to ameliorate these thermal differences and improve fish passage. As such, a temperature study was initiated in spring 2011 to identify the temperature regimen in the ladder as well as the immediate forebay region near the ladder exit. This report summarizes the results of that investigation.

## 2.0 METHODS

Twenty-two recording temperature sensors were used for the study. Six of these were Seabird Model 39 sensors that included temperature and depth, and the remaining sixteen were Onset Hobo<sup>®</sup> Pro V2 thermistors. The sensors were individually anchored at four locations in the ladder, on three vertical strings near the ladder exit, and in the fish collection channel (Figure 1).

The ladder instrumentation included three Seabird instruments that were deployed by the NWW water quality group and one Onset Hobo<sup>®</sup> that was installed by the Lower Granite Fish Passage Unit. The three Seabird probes were placed at the Entrance, Section 16, and Exit 1. Each probe was housed in an open section of galvanized pipe for protection and cabled to ladder rungs. One Onset sensor was located at Exit 2 and also cabled in place.

The forebay sites consisted of thermistor strings at three locations. Two of these locations (i.e., the Ladder Exit and Diffuser) were composed of weighted cables that were attached to the railing. As such, the true sensor depth changed throughout the deployment period as a function of the forebay elevation (Figure 2). The third temperature string (i.e., 30-ft Out) was attached to a float that enabled the sensors to remain at the same depths relative to the water surface.

- At the Ladder Exit, Onset Hobos<sup>®</sup> were initially placed at approximately 20, 40, and 60 and 75 feet below the surface. A Seabird probe also placed at the bottom depth.
- At Diffuser 14, three Onset thermistors were initially attached to the cable at 20, 40 and 60 feet below the surface, along with two additional Hobos<sup>®</sup> and a Seabird probe at approximately 75 ft.
- At the Ladder Exit 30-ft Out location, the cable was shackled to an old floating wooden structure. Onset Hobos<sup>®</sup> were placed at 6.5, 20, 40, and 60 feet below the surface. Another Onset Hobo<sup>®</sup> and a Seabird probe were attached at a depth of approximately 77 feet. Bottom sensor depths recorded by the Seabird over the study period fluctuated by less than 1.25 feet.

One Onset Hobo<sup>®</sup> was also placed within the dam in the fish collection channel. This channel feeds into the juvenile fish bypass conduit that transports downstream migrants to the juvenile fish facility. Water from the collection channel does not enter the adult fish ladder.

The thermistors that were installed by NWW and the Fish Passage Unit were in place for slightly different time periods. The District sensors were deployed from 21 May 2011 to 17 October 2011 while the Project units were in place from 5 June to 5 October. All of the thermistors were programmed to record data at hourly intervals. The NWW probes remained undisturbed until the

data was downloaded at the end of the study, while the Project data loggers were downloaded on 31 July.

The accuracy of the NWW Onset and Seabird thermistors were checked by placing them in an Omega thermoregulated water bath prior to deployment. The Onset Hobos<sup>®</sup> were within the manufacturer's specification of  $\pm 0.2$  degrees Celsius ( $^{\circ}\text{C}$ ). The Seabird's have a stated accuracy of  $0.002^{\circ}\text{C}$  which could not be verified since this tolerance is more refined than the temperature regulation abilities of the water bath. However, the accuracy was assumed to be as good, or better, than the Onset Hobos<sup>®</sup>.

## **3.0 RESULTS**

### **3.1 Adult Fish Ladder**

#### **3.1.1 *Location Comparisons***

Calculated daily averages for the four ladder temperature recorders are shown in Figure 3. Daily averages are used for an initial portrayal of the data since is eliminated diurnal variability and makes the overall trends more apparent in the graph. The daily averages were essentially the same from the beginning of the study to early July and after mid-September. Data from the Exit 1, Exit 2, and Section 16 locations at the upper end of the ladder are very similar, with maximum daily averages ranging from  $21.8$  to  $21.9^{\circ}\text{C}$  compared to  $20.2^{\circ}\text{C}$  for the sensor at the Entrance.

About 78% to 79% of the hourly data recorded in the ladder between 1 July and 30 September were greater than  $18^{\circ}\text{C}$  (Figure 4; Table 2). However, the frequency distributions that were determined for the data sets above this threshold did show differences. At the Entrance location, 75% of the hourly data were between  $18^{\circ}\text{C}$  and  $20^{\circ}\text{C}$ . In comparison, at the upper three locations in the ladder, 42% to 43% of the data were within that temperature range whereas 64% of the data were between  $19^{\circ}\text{C}$  and  $21^{\circ}\text{C}$ . Additionally, 36% to 37% of the data from the upper three locations were greater than  $20^{\circ}\text{C}$  compared to 3.5% at the Entrance.

#### **3.1.2 *Diel Differences***

Diel differences were also examined for the hourly ladder data. Figure 5 shows that the difference between daily maximum and minimum temperatures at the Entrance displayed the least amount of variability throughout the study. A frequency analysis further illustrated that almost 98% of the diel fluctuations were less than or equal to  $1^{\circ}\text{C}$  during the 1 July through 30 September period (Table 3).

The diel differences at the three upper locations tracked each other quite well (Figure 5) and were usually greater than the corresponding calculations from the lower two stations (the exception being Unit 1 prior to 1 August). The maximum daily difference for the entire study period was  $2.9^{\circ}\text{C}$  at all three locations. Between 1 July and 30 September, 59% to 62% of the daily differences were greater than  $1^{\circ}\text{C}$  and 13 to 15% of the differences were greater than  $2^{\circ}\text{C}$  (Figure 6; Table 3).

### **3.2 Forebay**

#### **3.2.1 *Temperatures at Depth***

The daily average data from all depths at each of the three forebay stations displayed similar temperatures prior to about 24 July and after mid-September (Figure 7; Tables 4 through 9). The two locations closest to the dam (i.e., Ladder Exit and Diffuser) showed the highest temperatures at a depth of approximately 20 ft. Between 1 July and 30 September about 43% of the hourly data were greater than  $20^{\circ}\text{C}$ . Furthermore, 73% to 80% of the hourly data was greater than

18 °C during the same period. Water temperatures exceeded 22 °C at a depth of 20 ft between 28 July and 29 August. Water temperatures decreased with depth, but between 1 July and 30 September 74% to 79% of the hourly measurements were still greater than 18 °C (Figures 8 and 9; Tables 5 and 7).

Water temperatures at the 30-ft Out station displayed a slightly different temperature regimen during the summer than the two strings adjacent to the dam. The sensor located at a depth of 6.5 ft also experienced temperatures greater than 20 °C 43 % of the time between 1 July and 30 September. However, at a depth of 20 ft only 25% of the hourly measurements were greater than 20 °C – less than the percentage noted for the two strings adjacent to the dam.

Approximately 80% of the hourly data were greater than 18 °C at the 6.5 ft and 20 ft depths. The water temperatures were progressively cooler with depth, and only 8.5% of the hourly data were greater than 20 °C at 40 ft and 0.9% at 77 ft. However, 75 to 78% of the data were still greater than 18 °C (Figure 10 and Table 9).

### **3.2.2 Diel Fluctuations**

Diel temperature fluctuations at all three forebay locations were greatest from about 1 July to mid-September (Figure 11). Daily differences at the 20-ft depth at the Ladder Exit and Diffuser locations ranged from less than 0.5 °C to almost 3.5 °C during this period (Figure 12 and 13; Tables 10 and 11). Approximately 65 percent of the daily fluctuations were greater than 1 °C at this depth, and a third of the days showed temperature fluctuations that were greater than 2 °C (Figures 12 and 13). The diel differences at the Ladder Exit were less accentuated at the 40, 60, and 75-ft depths than at the corresponding Diffuser location. Eighty-two to 90% of the daily fluctuations were less than 1 °C at these Ladder Exit depths. The primary exceptions occurred during the first ten days of September when the differences exceeded 2 °C (Figure 11). The diel difference frequencies at the Diffuser depths of 60 and 75 ft were similar to those at the Ladder Exit with 83% and 92% less than 1 °C, respectively. The primary excursions again occurred during the first ten days of September. The sensor at the 40-ft depth recorded greater daily variability; 66% of the time the fluctuations were less than 1 °C, yet 24% were between 1.0 to 1.5 °C and almost 10% were greater than 1.5 °C. Most of these excursions occurred during two periods; mid-July and from mid-August to early September.

The diel differences at the 30-ft Out location showed some similarities to the near-dam locations, but shifted to different depths (Figure 11). Sixty-four percent of daily differences were greater than 1 °C (Figure 14 and Table 12) and there were four days when the diel fluctuation exceeded 3 °C during the 1 July to 30 September period – these results are very similar to the ones determined for the 20-ft depth at the Ladder Exit and Diffuser. At the 30-ft Out depth of 20-ft, 61% of the diurnal differences were less than 1 °C. However, as noted for the 40-ft Diffuser depth, there were days during mid-July and from mid-to-late August when diel variability exceeded 2 °C. At the 40 ft, 60 ft and 75 ft depths diel variability was less than 1 °C from 83% to 89% of the time (Table 12).

It should be mentioned at previous studies completed for RPA 132 showed that temperature variability near the upstream dam face was influenced by project operations. It is possible that project operations also influenced the temperatures recorded at the Exit and Diffuser locations, but a more detailed analysis correlating unit operations to temperature would be needed to elicit any relationships.

### 3.2.3 Comparisons at Specific Depths

Temperature differences at the same forebay station depths were also considered. Line graphs of mean daily temperatures show that differences were most common during the 1 July through September time frame (Figure 15). The bulk of the hourly differences at all depths were between -0.5 °C and +0.5 °C.

The temperature differences were most noticeable at the 20-ft depth. Seventy-four percent of the hourly differences between the Ladder Exit and Diffuser were between -0.5 °C and 0.0 °C (Figures 16 and 17; Table 13), indicating that temperatures at the Diffuser were generally greater than at the ladder. Diffuser temperatures were also greater than 30-ft Out temperatures approximately 76% of the time, and 21% of the time these differences exceeded 1 °C at 20 ft. Finally, Ladder Exit temperatures were greater than 30-ft Out temperatures 57% of the time, and about half of these were in the 0.0 °C to 0.5 °C range.

Temperature differences at 40 ft were less extreme than at 20 ft. Eighty-nine to 99.9% of the hourly differences were between -0.5 and +0.5 °C. As at the 20-ft level, Diffuser temperatures were greater than the comparable Ladder Exit and 30-ft Out temperatures. Ladder Exit and 30-ft Out temperatures were very similar with the differences split almost equally between -0.5 °C to 0.0 °C and 0.0 to 0.5 °C.

At the 60-ft depth, Diffuser temperatures were again greater than the comparable measurements at the Ladder Exit. This occurred approximately 73% of the time and ranged up to 2 °C. 30-ft Out temperatures were greater than Ladder Exit temperatures almost 100% of the time, but 92% were within the 0.0 °C to 0.5 °C range. 30-ft Out temperatures were also greater than Diffuser temperatures by 0.0 °C to 0.5 °C about 60% of the time.

### 3.3 Fish Collection Channel

The temperature of the water in the fish collection channel most closely resembles the temperatures recorded at the deeper forebay monitoring sites (Figure 18). From 1 July through 30 September, the mean daily temperature was 18.3 °C while the maximum was 19.8 °C – virtually the same results that were calculated for the Ladder Exit at 60 ft, Forebay Diffuser at 75 ft, and the 30-ft Out location at 77 ft. None of the 1 July through 30 September hourly temperatures exceeded 20 °C and approximately 76% were between 18 °C and 20 °C (Figure 19, Table 14).

Diel temperatures determined for the Unit 1 are shown in Figure 20. The difference between maximum and minimum temperatures only exceeded 1.2 °C on two days (i.e., 22 June and 16 July) during the study. Between 1 July and 30 September, almost 99% of the diel differences were less than 1 °C and 65% were less than 0.5 °C (Figure 21, Table 15).

## 4.0 SUMMARY

Some of the salient results from this investigation include:

### Adult Fish Ladder

- The warmest water and largest differences between the upper and lower sections occurred between 1 July and the latter part of September
- The temperatures at the three upper locations were very similar and maximum daily average temperatures were close to 22 °C between 1 July and 30 September. Comparable temperatures at the two lower locations were about 20 °C.

- Diel differences were greater at the three upper locations than at the Entrance by 1.7 °C. The sensor at Unit 1 displayed temperature fluctuations similar to those determined at the upper end until August 1, but more closely tracked the sensor located at the Entrance after that date.

#### Forebay

- Daily maximum temperatures the 20-ft depth at the Ladder Exit and Diffuser locations were approximately 2 °C greater than at the 30-ft Out location, and the mean daily temperatures for the 1 July through 30 September period were 0.5 °C higher near the dam. Daily maximum and mean temperatures at the remaining depths were up to 0.4 °C different at a given depth, but were often the same. Previous temperature studies at the upstream dam face have shown that downwelling due to project operations affects temperature variability.
- Hourly data from the Ladder Exit and Diffuser indicated that temperatures at 20, 40, and 60 ft were warmer by up to 2.3 °C at the Diffuser between 1 July and 30 September, but the average differences were less than 0.5 °C for this time period. A similar evaluation between the Diffuser and 30-ft Out locations indicated that on an hourly basis Diffuser temperatures were 2.5 °C to 3.5 °C warmer, but the average for the period was less than 0.5 °C.
- Diel differences at the Ladder Exit and Diffuser 20-ft depth, as well as at the 30-ft Out 6.5-ft depth were greater than 1 °C 64% to 66% of the time between 1 July and 30 September. Eighty-three percent to 92% of the daily fluctuations were less than 1°C at the 40-ft, 60-ft, and bottom depths at the Ladder Exit and 30-ft Out locations, as well as at the Diffuser 60-ft and 75-ft depths. Approximately 66% of the diurnal differences were less than 1 °C at the 40-ft Diffuser depth.

#### Fish Collection Channel

- Recorded water temperatures and frequency distributions for the fish collection channel were similar to those determined at the deeper depths of the forebay strings.

# **FIGURES**

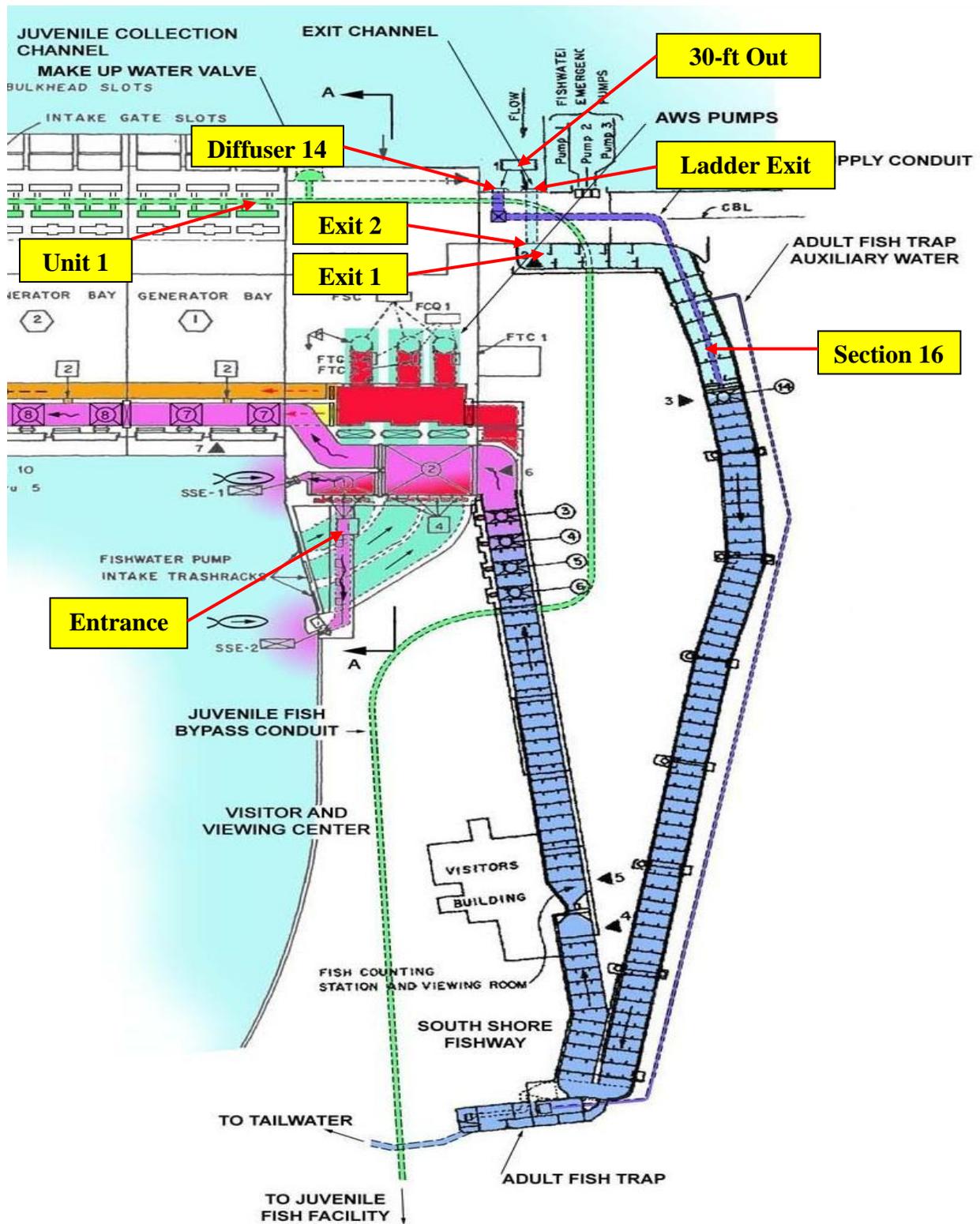
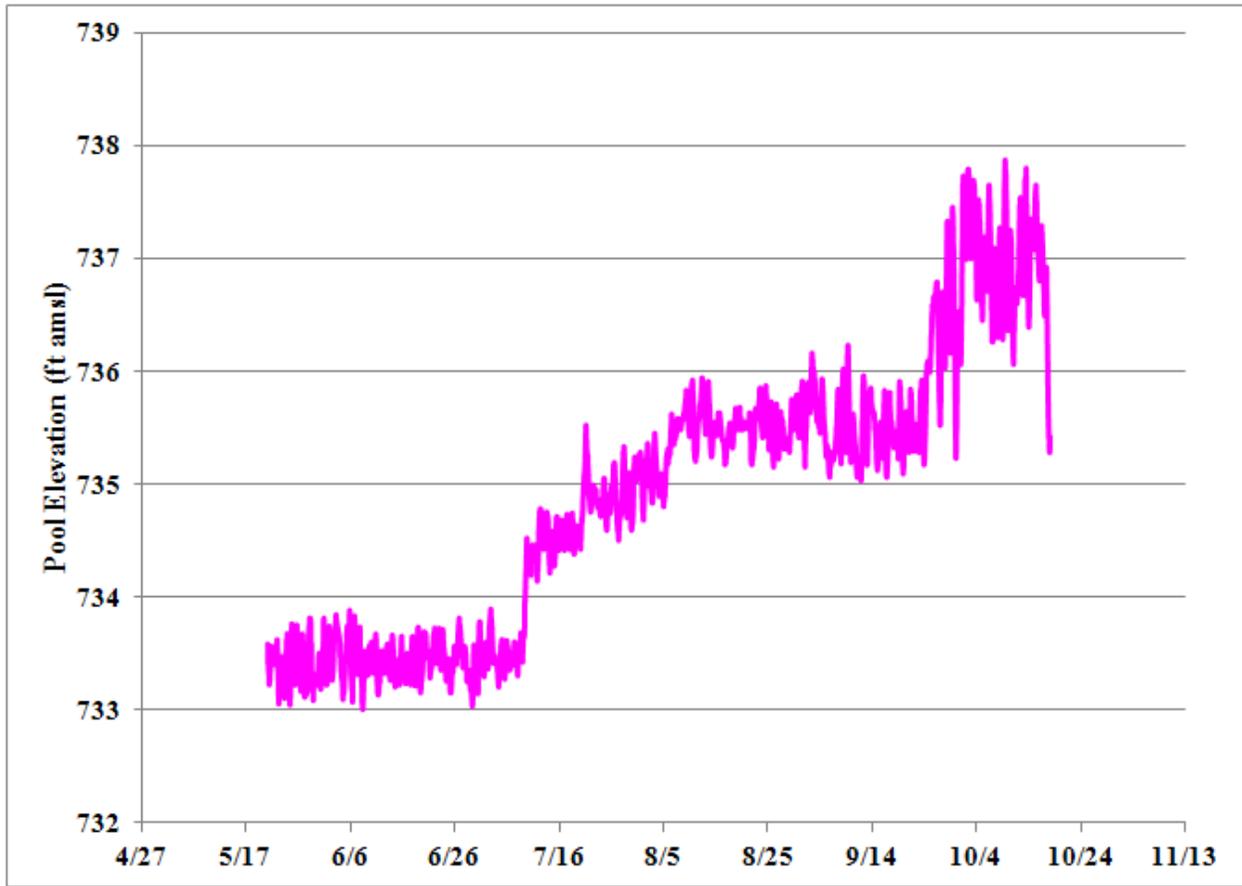
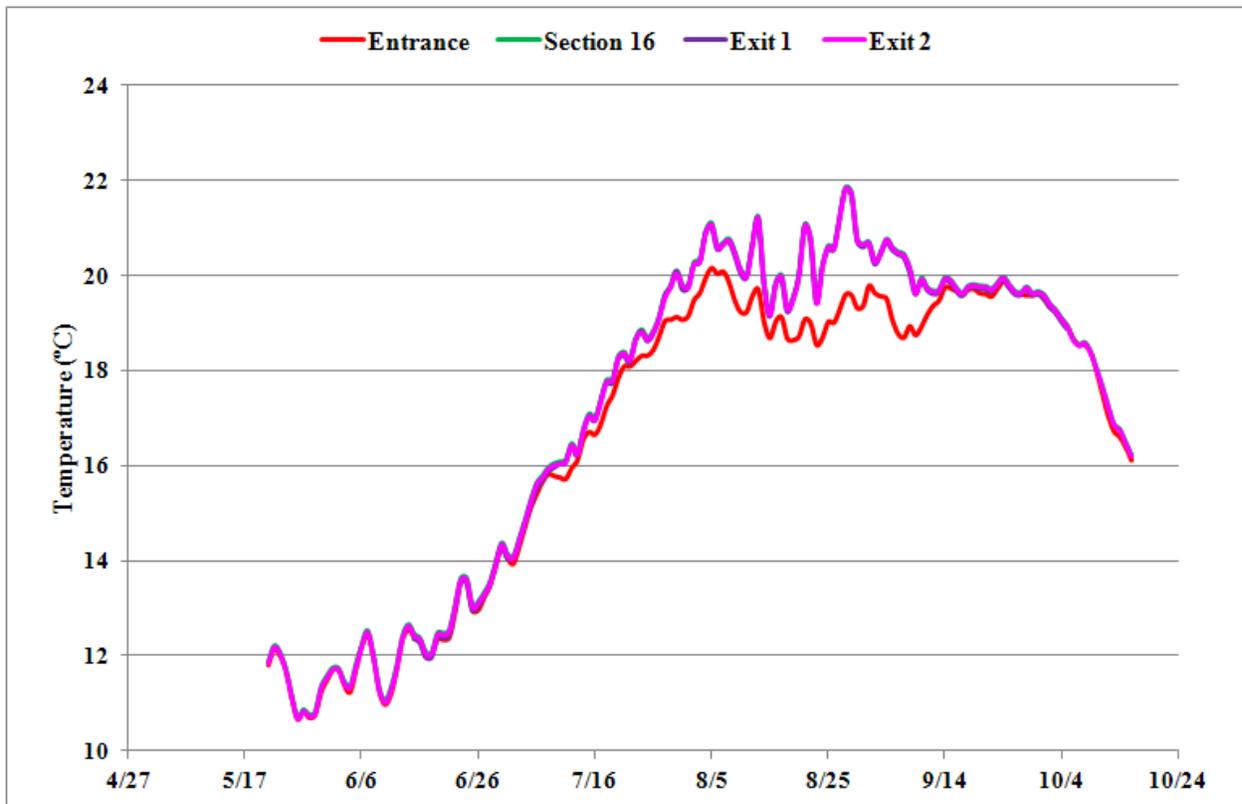


Figure 1. Locations in the Lower Granite fish ladder and forebay where the temperature sensors were deployed during 2011.



**Figure 2. Lower Granite pool elevations between 21 May 2011 and 17 October 2011.**



**Figure 3. Daily average temperatures calculated for the four fish ladder thermistors.**

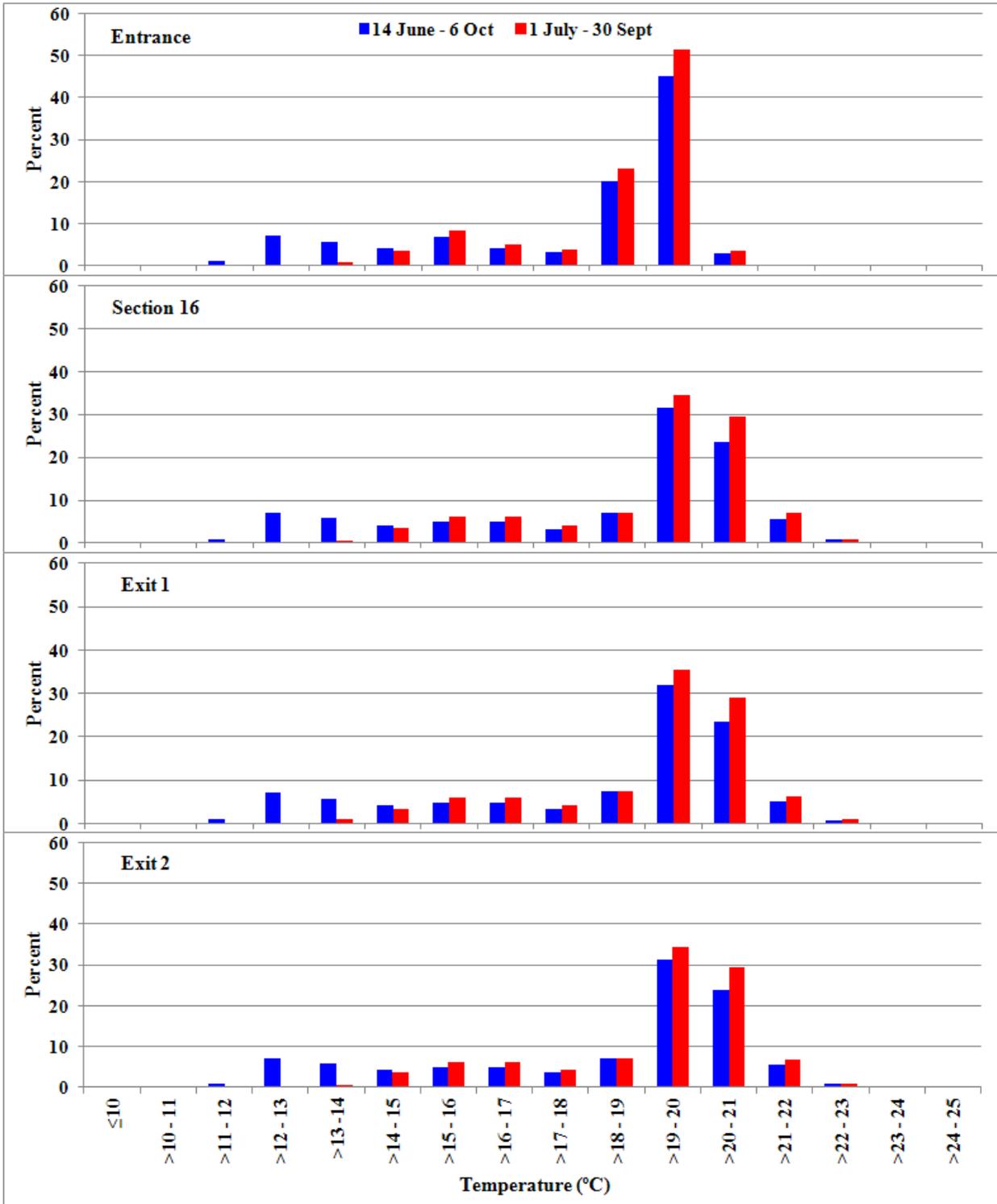
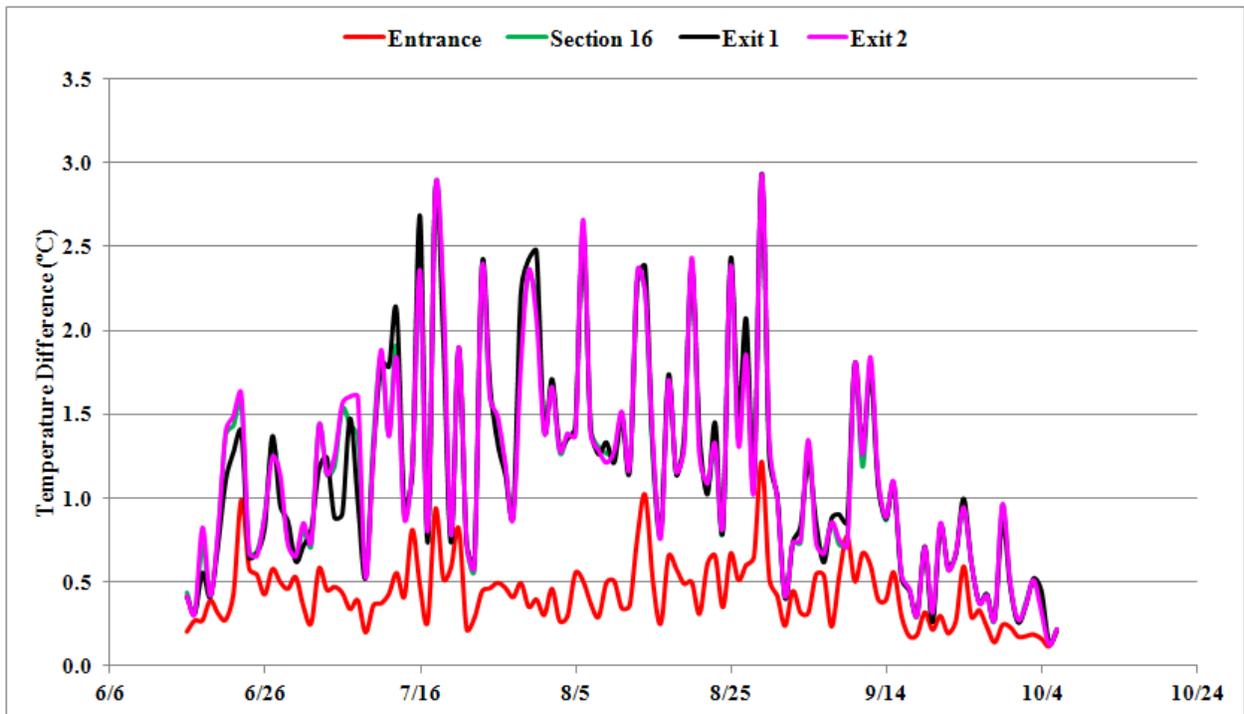


Figure 4. Frequency distributions for the hourly data measured at the four fish ladder thermistors.



**Figure 5. Diel temperature differences calculated for the four fish ladder thermistors.**

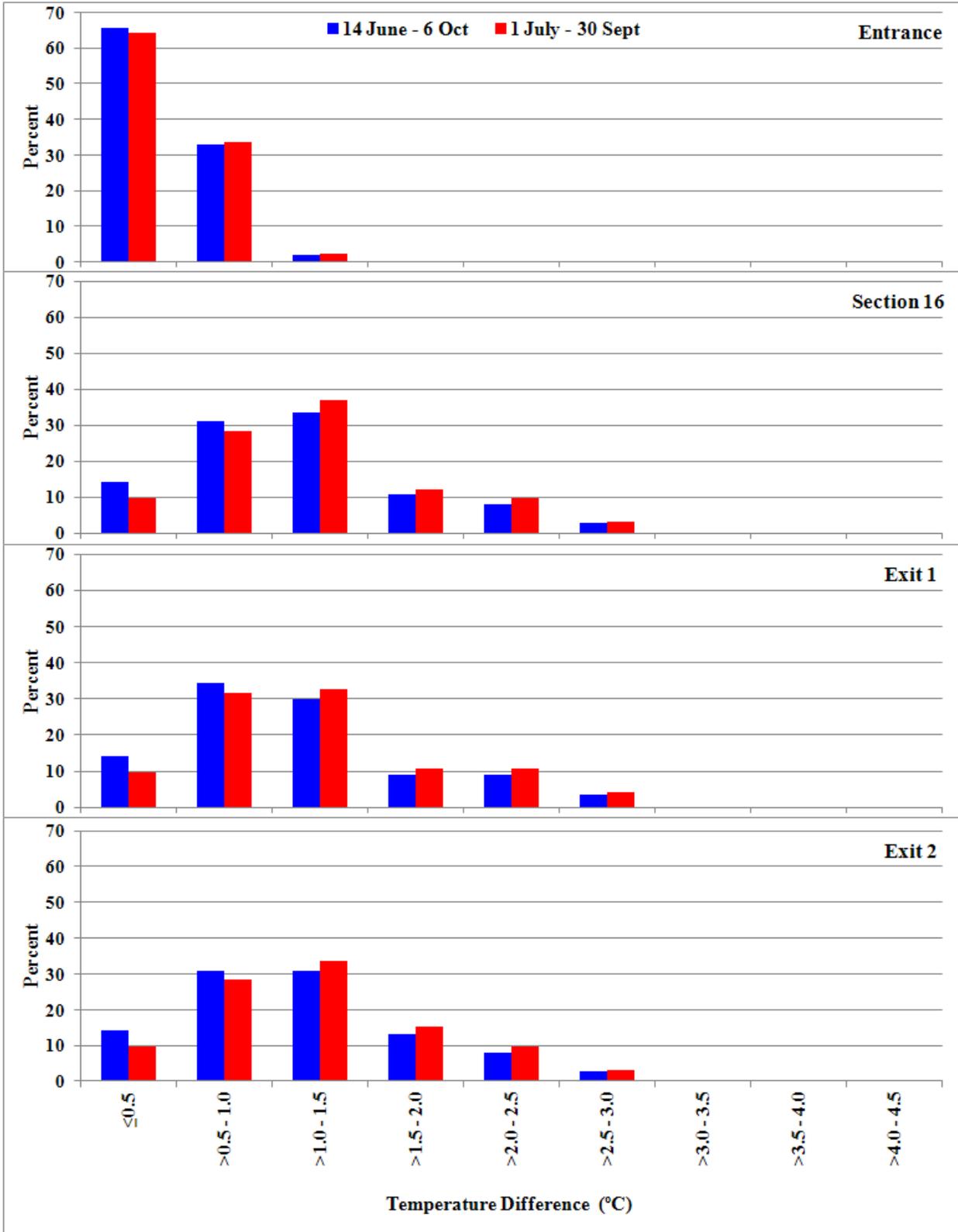


Figure 6. Frequency distributions for the diel temperature differences calculated for the four fish ladder thermistors.

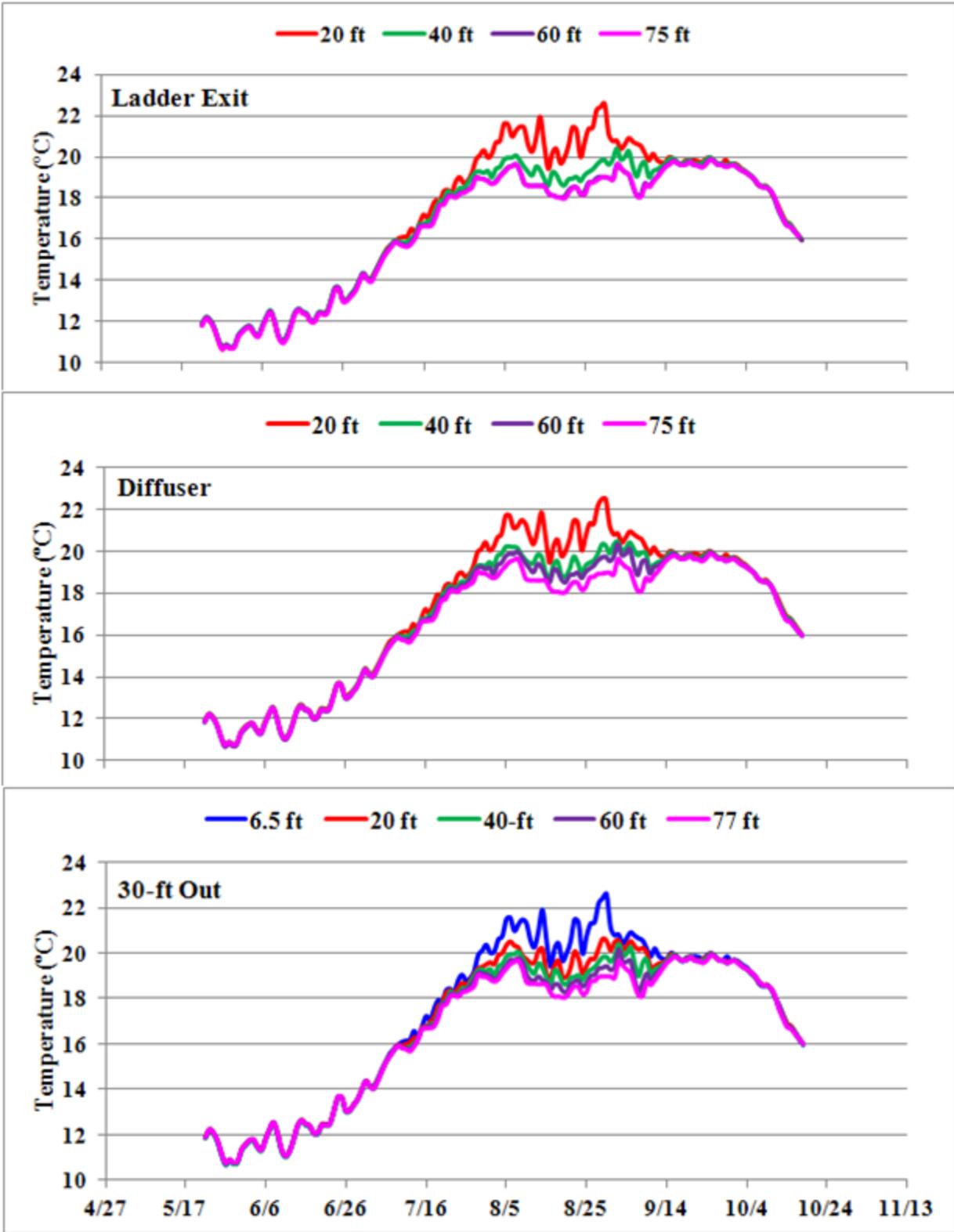


Figure 7. Line graphs of the average daily temperatures calculated for the three forebay temperature strings.

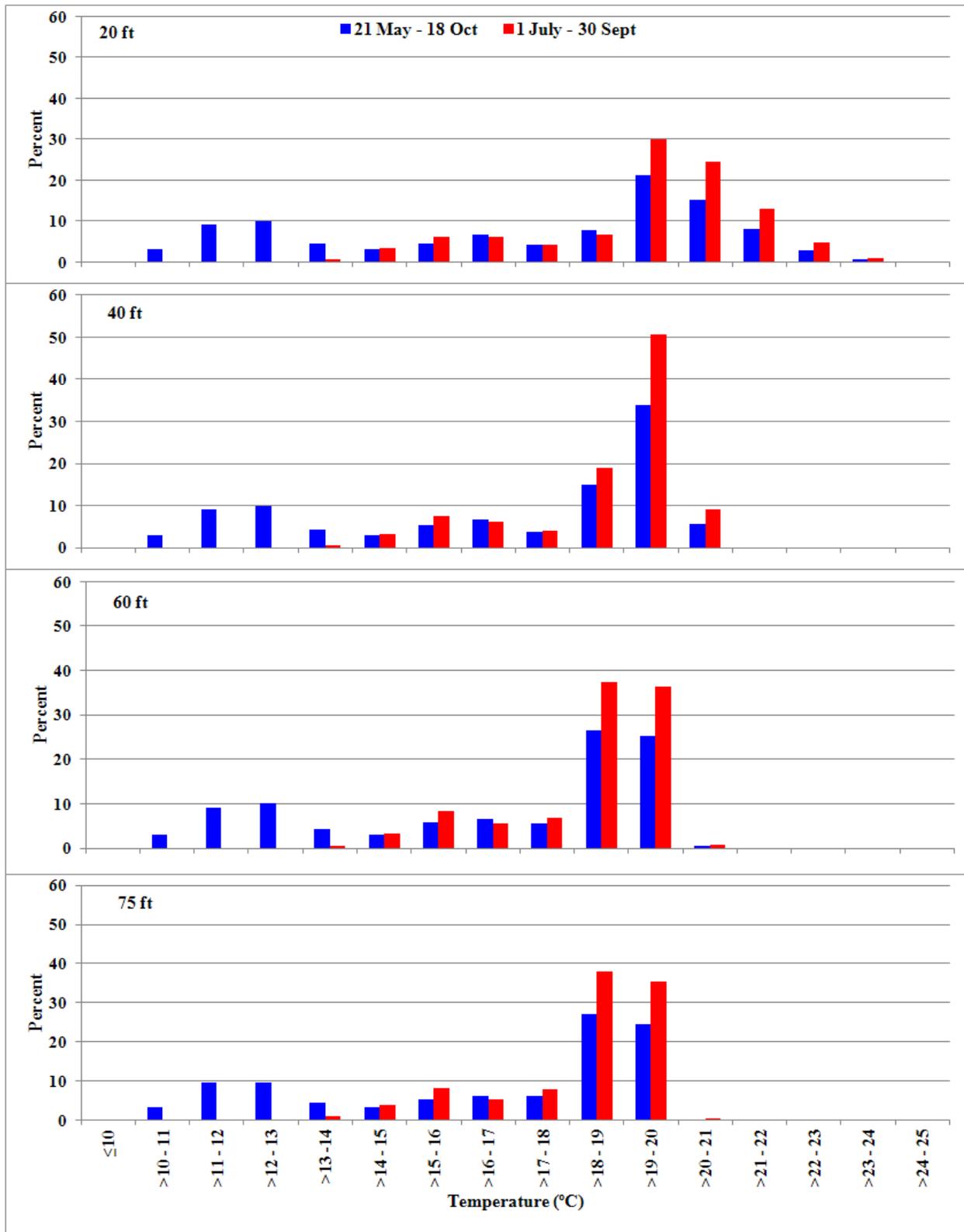


Figure 8. Frequency distributions calculated for the hourly data recorded at the Exit Ladder thermistor string.

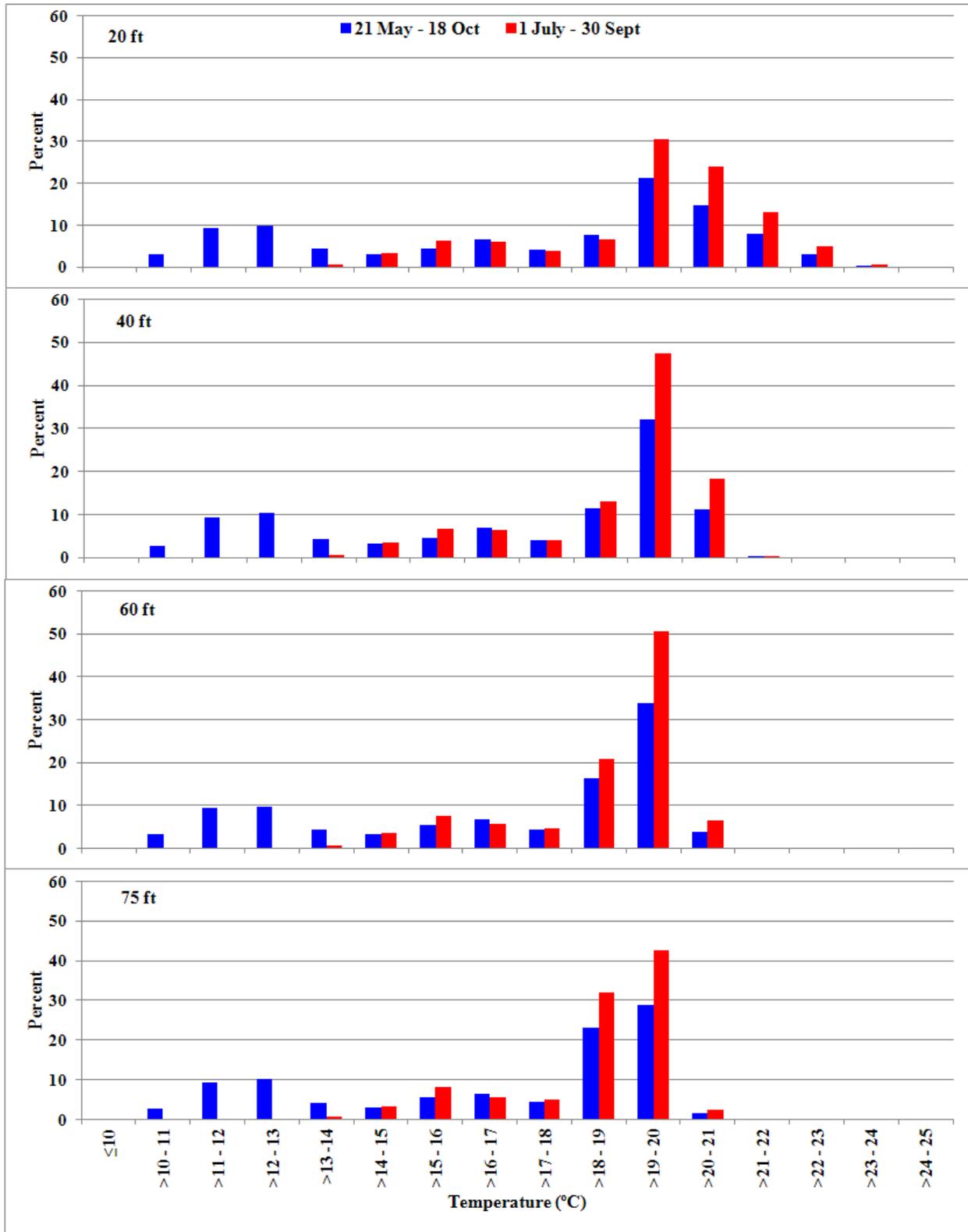


Figure 9. Frequency distributions calculated for the hourly data recorded at the Diffuser thermistor string.

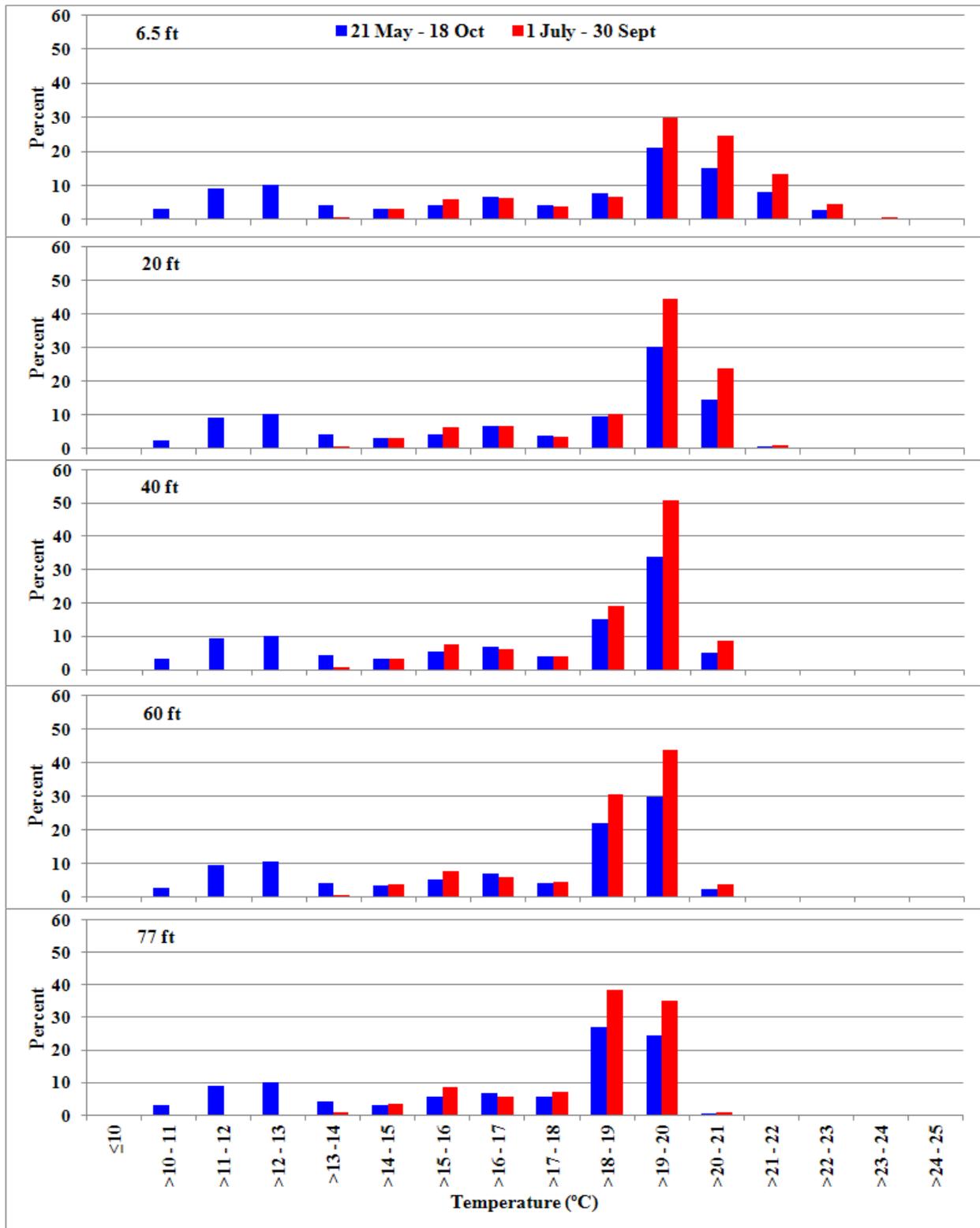


Figure 10. Frequency distributions calculated for the hourly data recorded at the 30-ft Out thermistor string.

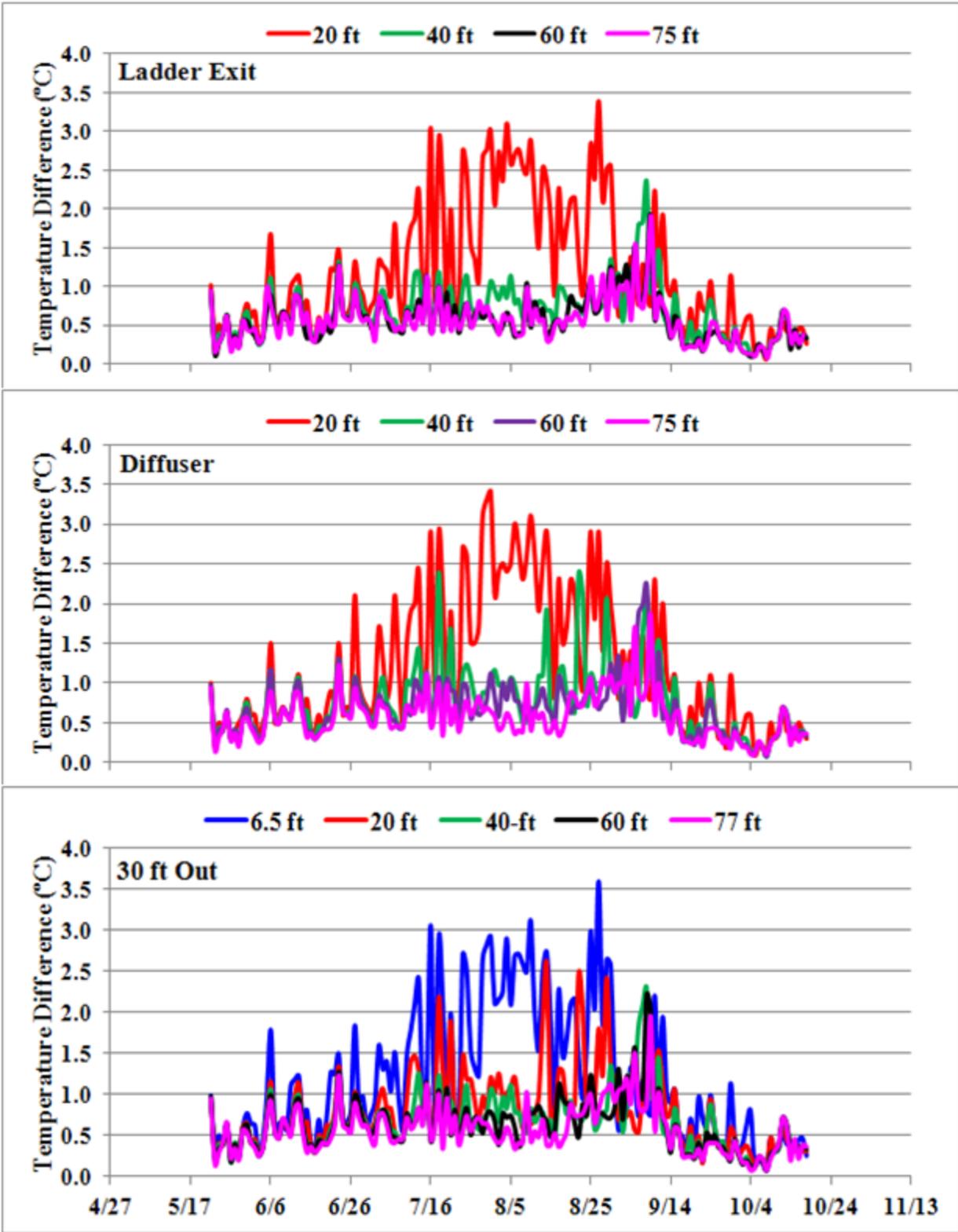


Figure 11. Diel temperature differences calculated for the three forebay temperature strings.

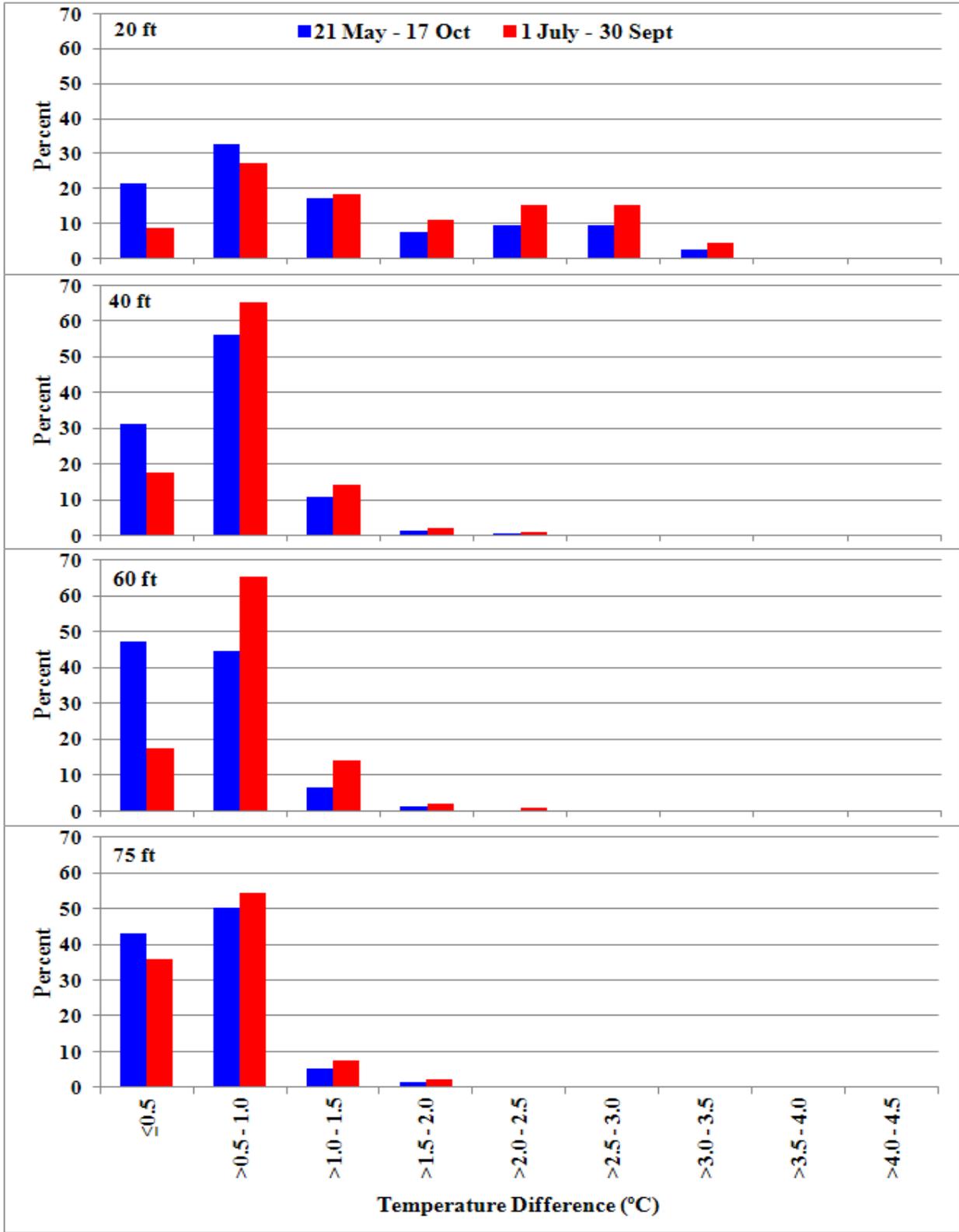


Figure 12. Frequency distributions for the diel temperature differences calculated for the Ladder Exit temperature string.

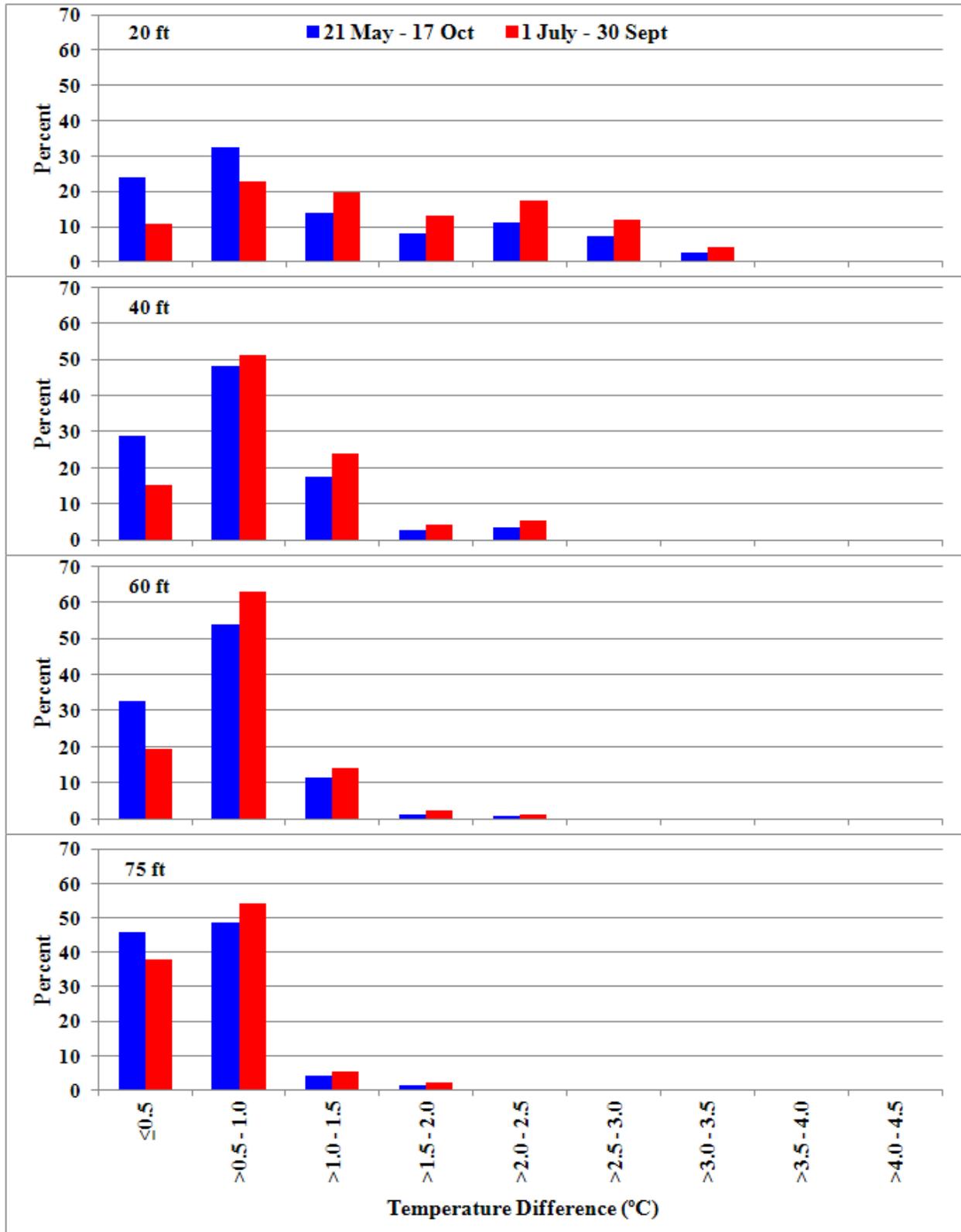


Figure 13. Frequency distributions for the diel temperature differences calculated for the Diffuser temperature string.

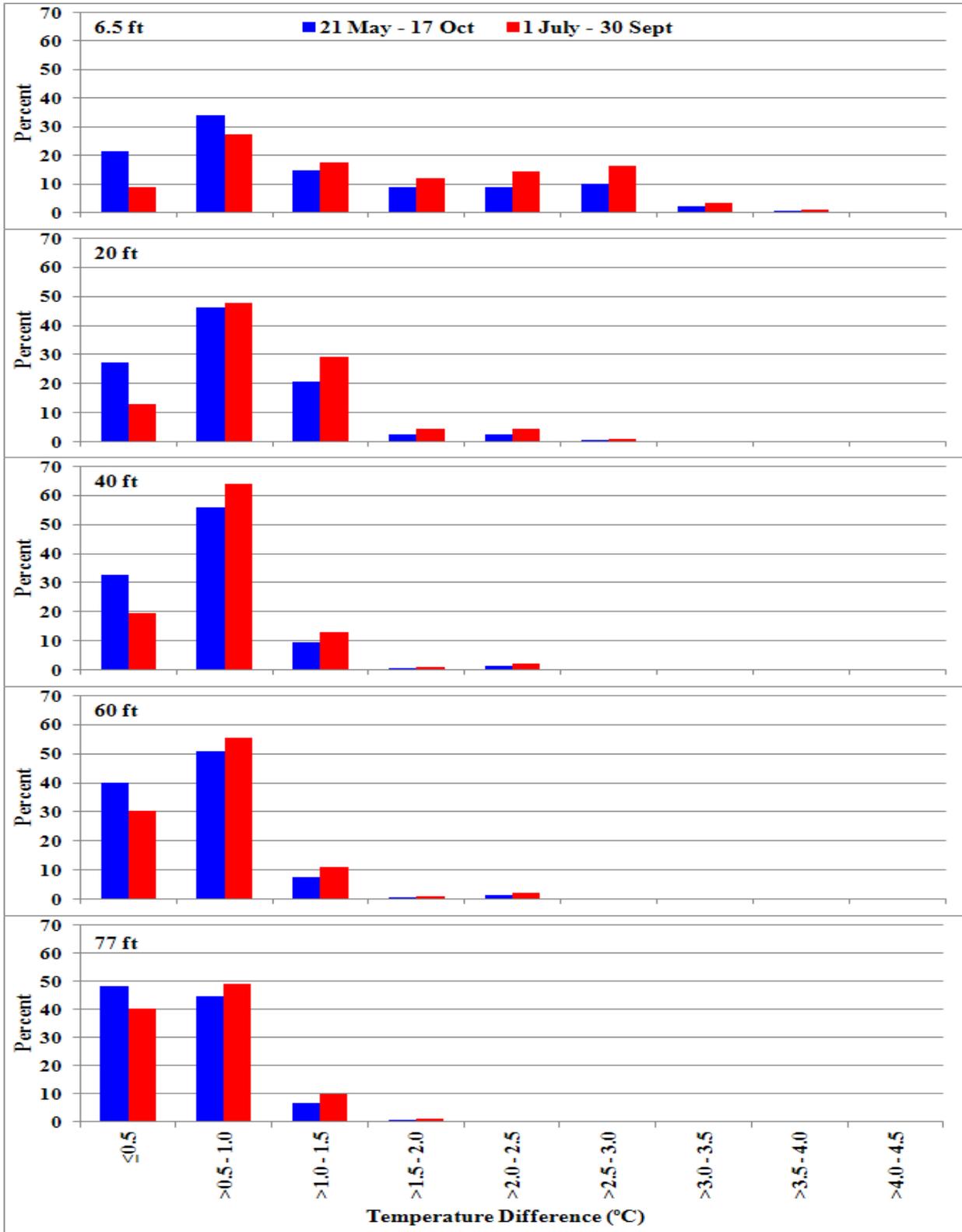


Figure 14. Frequency distributions for the diel temperature differences calculated for the 30-ft Out temperature string.

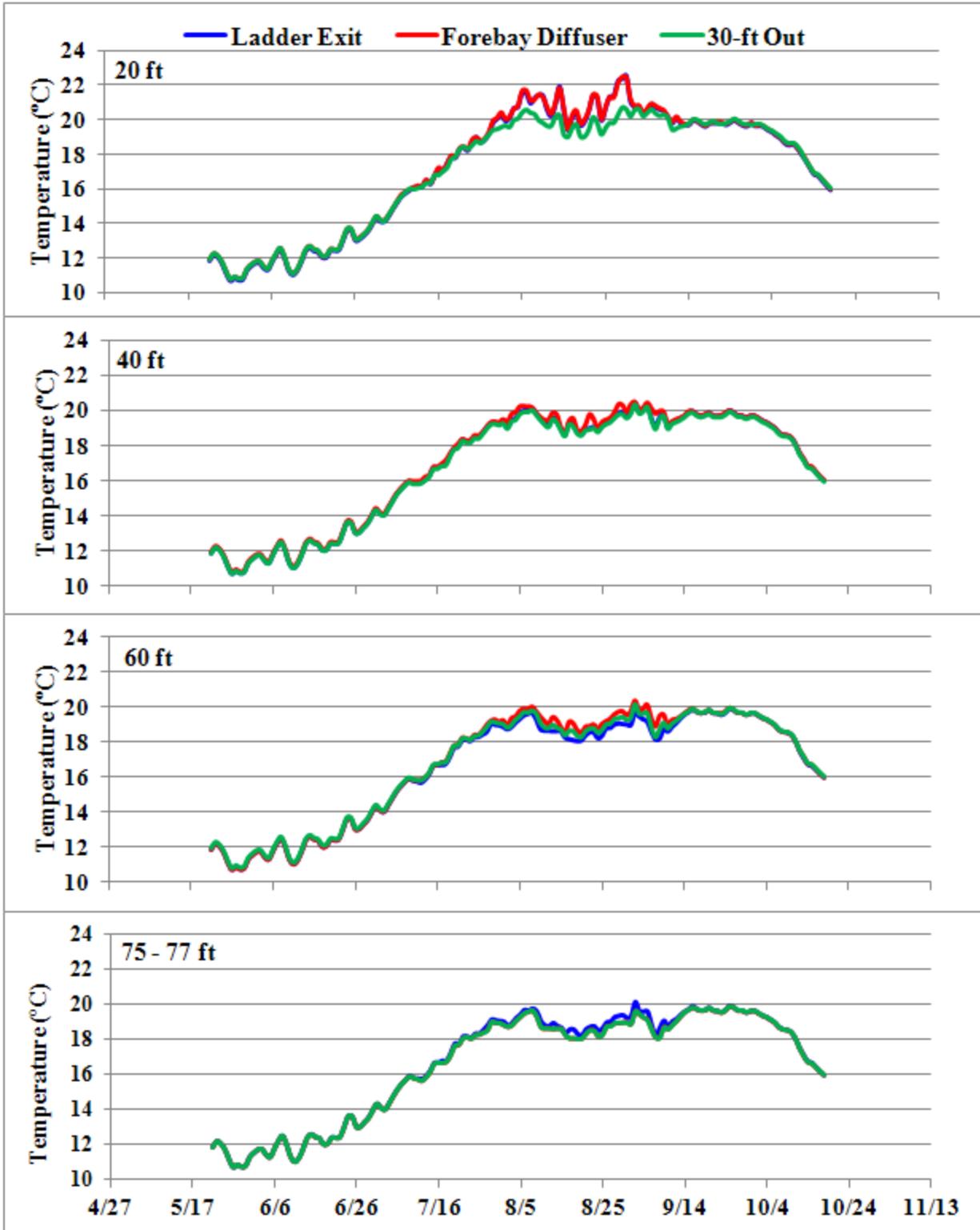


Figure 15. Average daily temperatures for the Ladder Exit, Forebay Diffuser, and 30-ft Out thermistors at selected depths.

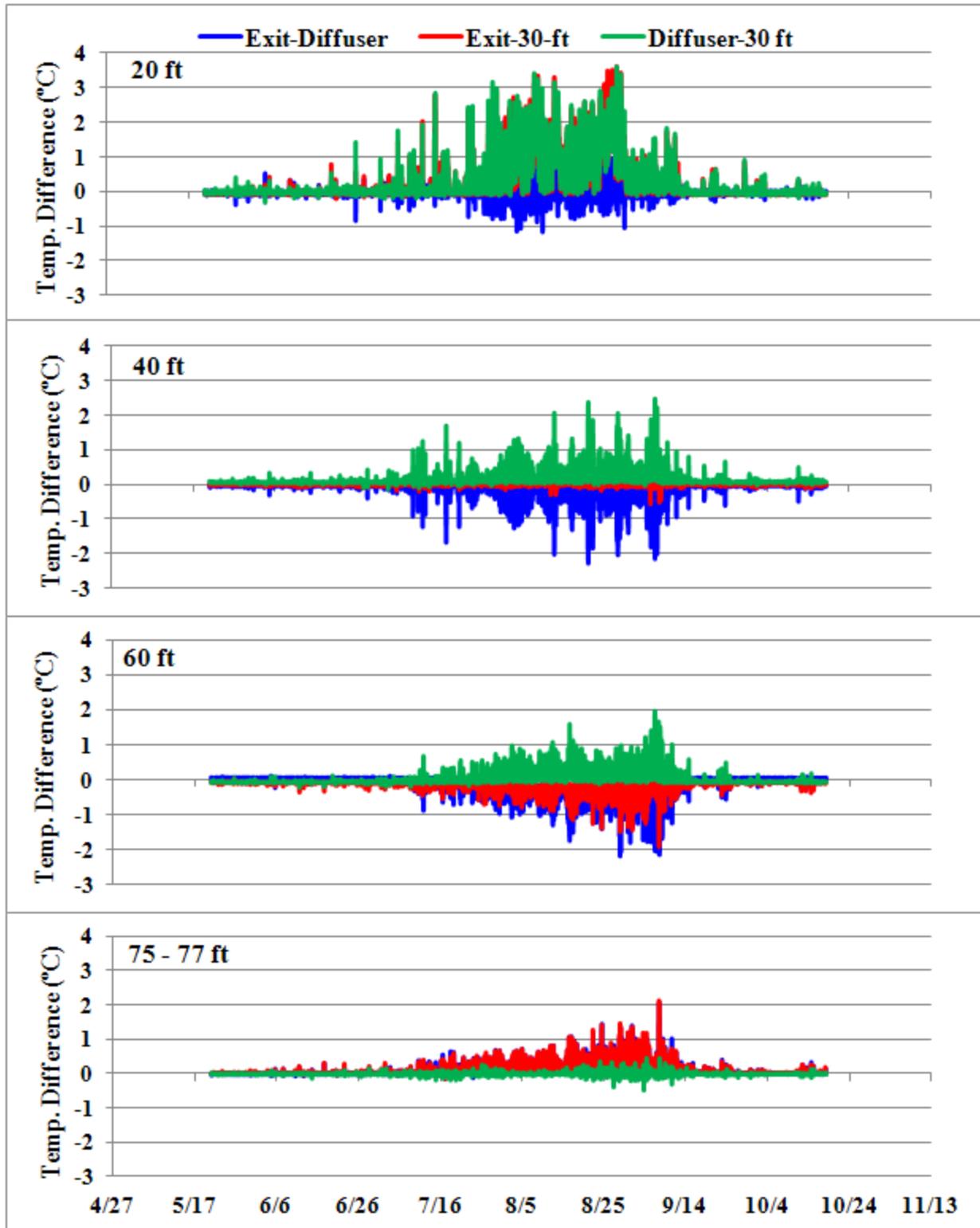


Figure 16. Hourly temperature differences calculated between forebay thermistors (i.e., Ladder Exit and Forebay Diffuser strings, Ladder Exit and 30-ft Out strings, as well as Forebay Diffuser and 30-ft Out strings) at selected depths.

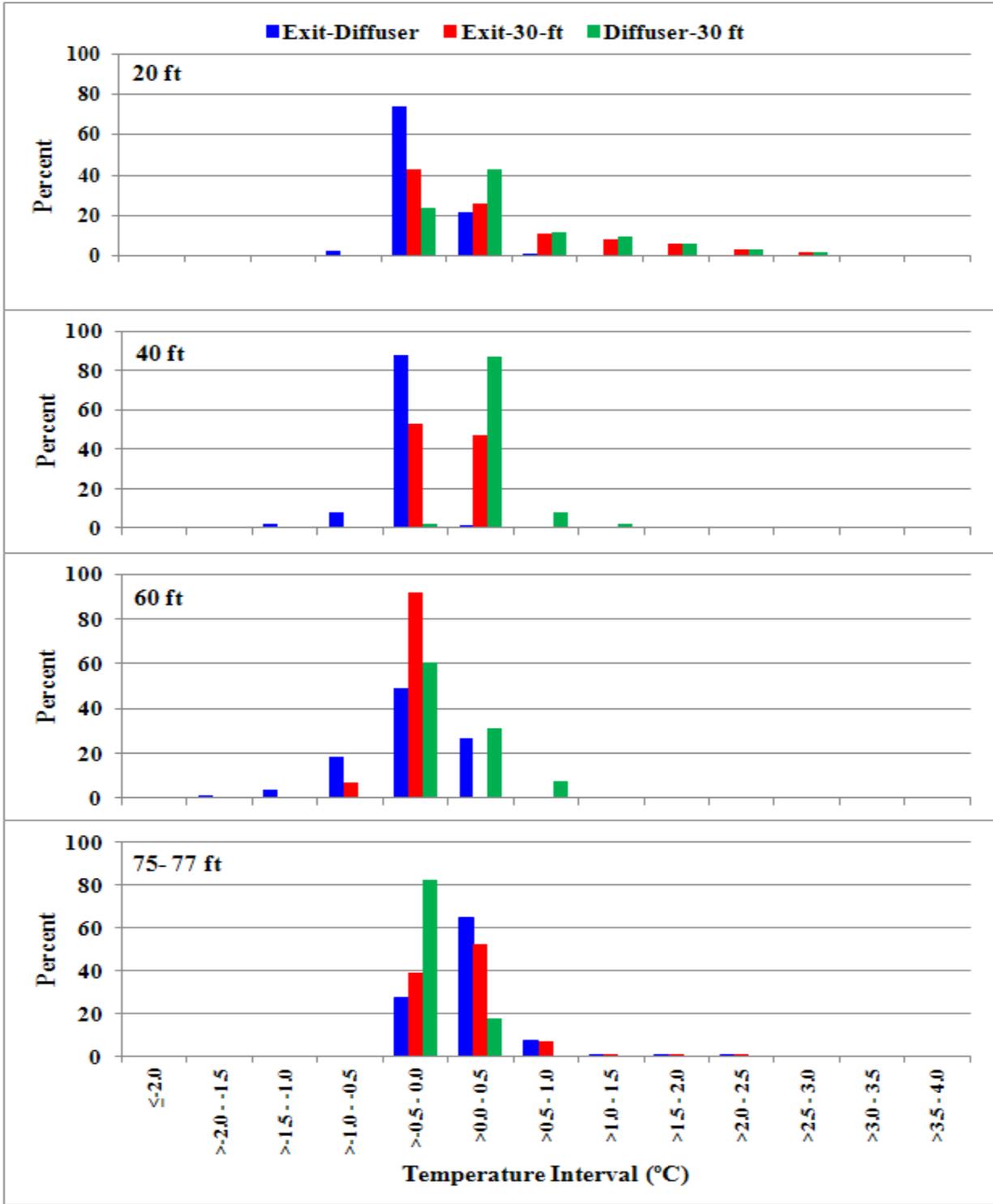


Figure 17. Frequency distributions determined for the hourly temperature differences calculated between forebay thermistors (i.e., Ladder Exit and Forebay Diffuser strings, Ladder Exit and 30-ft Out strings, as well as Forebay Diffuser and 30-ft Out strings) at selected depths during the 1 July through 30 September time period.

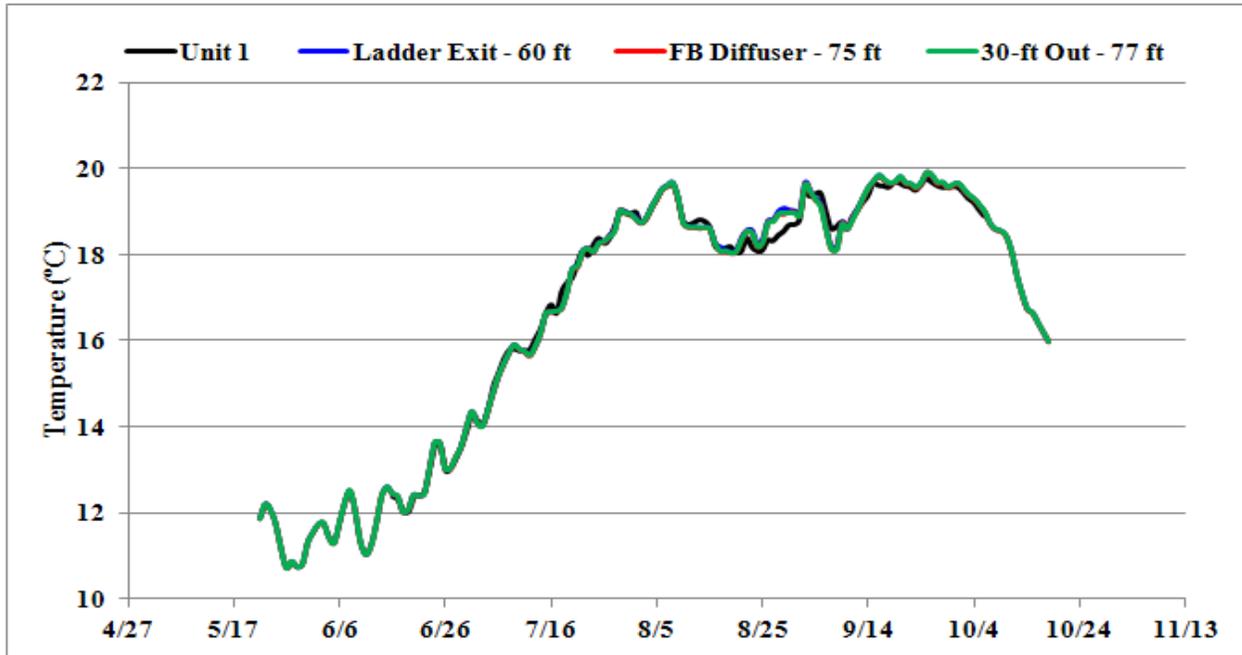


Figure 18. Daily average temperatures calculated for the data recorded by the Unit 1, Ladder Exit at 60 ft, Forebay Diffuser at 75 ft, and 30-ft Out at 77 ft thermistors.

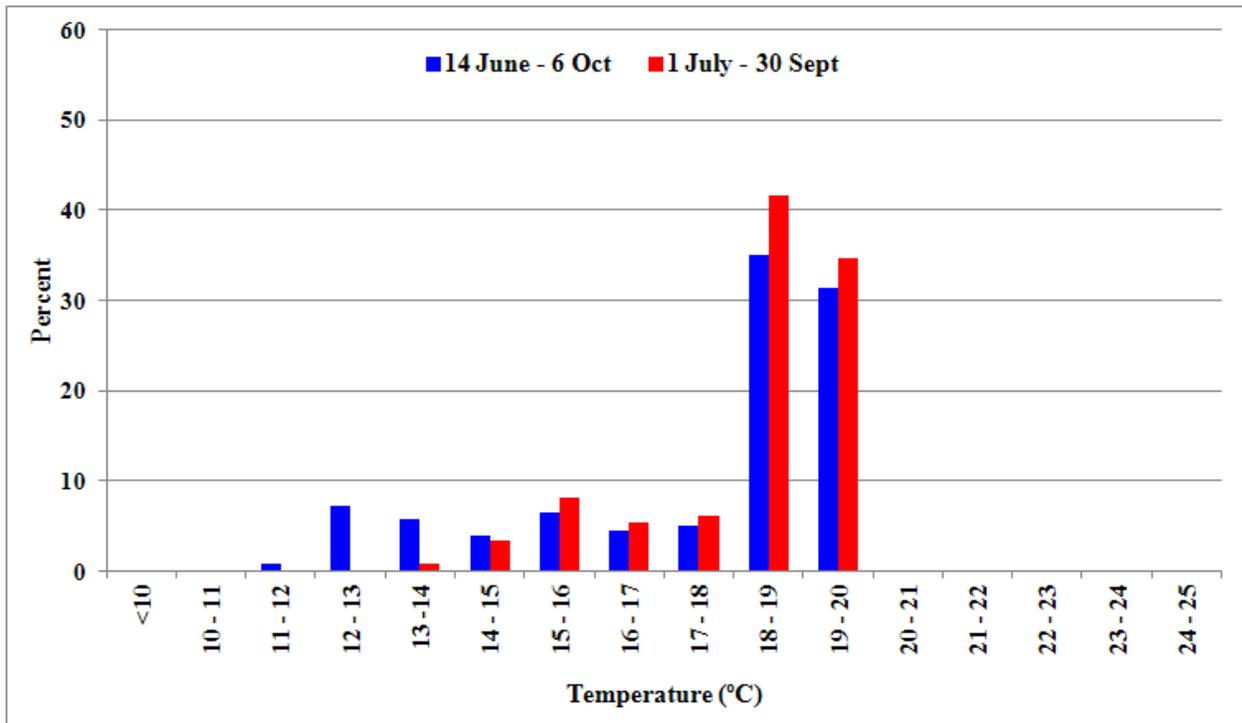
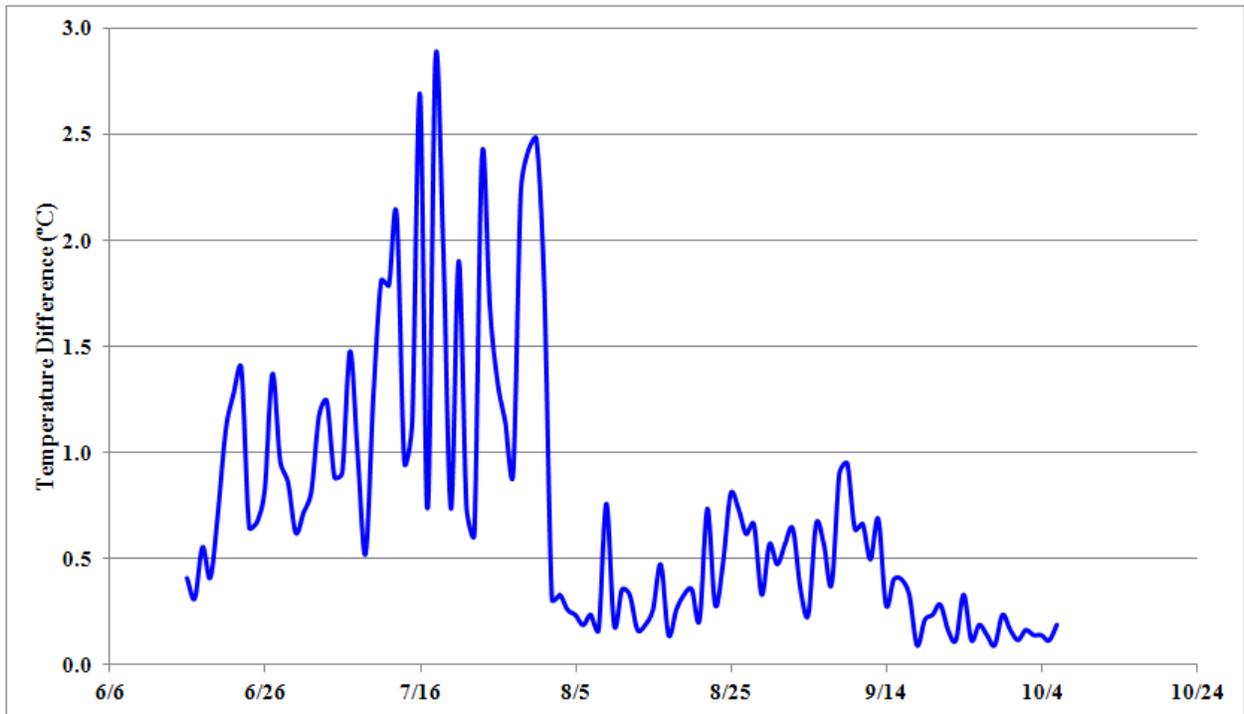
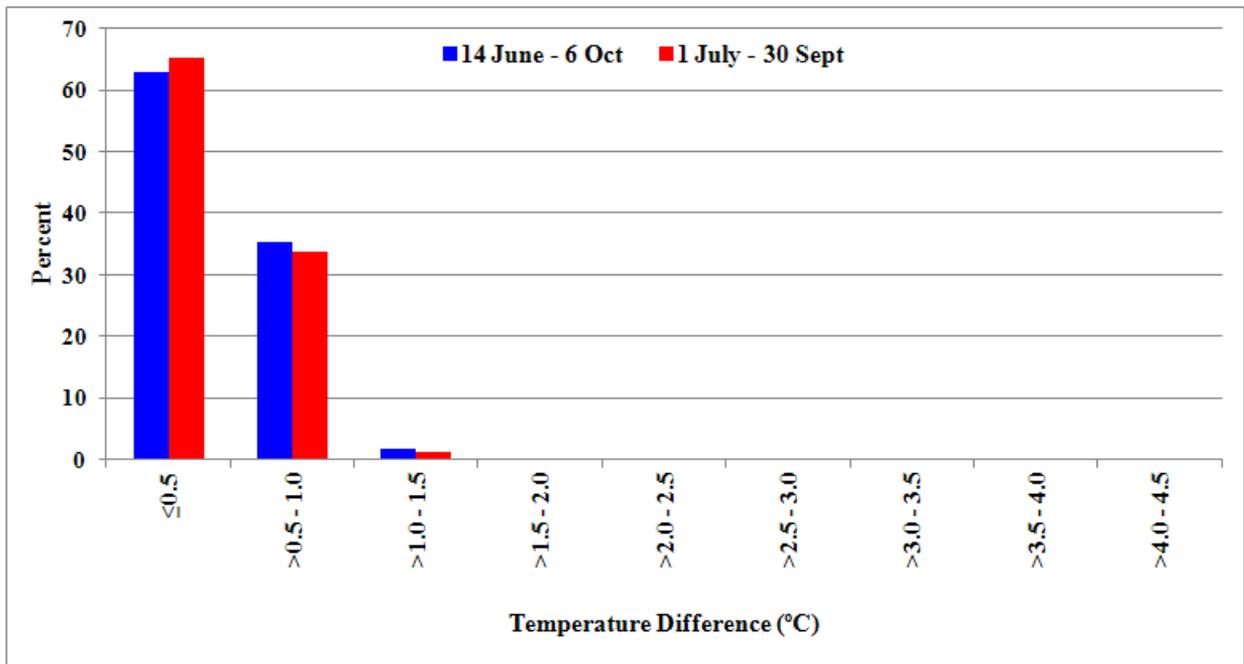


Figure 19. Frequency distributions calculated for the hourly data recorded at the Unit 1 thermistor.



**Figure 20.** Diel temperature differences calculated for the hourly data recorded by the Unit 1 thermistor.



**Figure 21.** Frequency distributions for the diel temperature differences determined in the fish collection channel at Unit 1 during the 14 June through 6 October and 1 July through 30 September periods.

# **TABLES**

**Table 1. Number of data points, minimum, maximum, and percent frequency distributions for the hourly thermistor data recorded in the adult fish ladder between 14 June 2011 and 6 October 2011.**

PARAMETER	LOCATION				
	ENTRANCE	SEC. 16	EXIT 1	EXIT 2	
Statistics	Data Count	2,738	2,738	2,738	2,738
	Min (°C)	11.9	11.8	11.8	11.8
	Max (°C)	20.4	23.4	23.4	23.4
Frequency Distribution by Percent	Temperature Interval (°C)				
	≤10	0.0	0.0	0.0	0.0
	>10 - 11	0.0	0.0	0.0	0.0
	>11 - 12	1.1	0.8	0.9	0.8
	>12 - 13	7.1	6.9	7.2	7.0
	>13 - 14	5.8	5.8	5.8	5.8
	>14 - 15	4.1	4.2	4.1	4.3
	>15 - 16	6.8	5.0	4.9	4.9
	>16 - 17	4.2	5.1	4.9	5.0
	>17 - 18	3.1	3.4	3.4	3.5
	>18 - 19	20.1	7.1	7.6	7.0
	>19 - 20	45.0	31.5	31.9	31.4
	>20 - 21	2.8	23.7	23.4	23.8
	>21 - 22	0.0	5.7	5.0	5.6
	>22 - 23	0.0	0.8	0.7	0.8
	>23 - 24	0.0	0.1	0.1	0.1
	>24 - 25	0.0	0.0	0.0	0.0

**Table 2. Number of data points, minimum, maximum, and percent frequency distributions for the hourly thermistor data recorded in the adult fish ladder between 1 July 2011 and 30 September 2011.**

PARAMETER	LOCATION				
	ENTRANCE	SEC. 16	EXIT 1	EXIT 2	
Statistics	Data Count	2,208	2,208	2,208	2,208
	Min (°C)	13.7	13.7	13.7	13.7
	Max (°C)	20.4	23.4	23.4	23.4
Frequency Distribution by Percent	Temperature Interval (°C)				
	≤10	0.0	0.0	0.0	0.0
	>10 - 11	0.0	0.0	0.0	0.0
	>11 - 12	0.0	0.0	0.0	0.0
	>12 - 13	0.0	0.0	0.0	0.0
	>13 - 14	0.8	0.6	1.0	0.6
	>14 - 15	3.6	3.4	3.5	3.6
	>15 - 16	8.4	6.3	6.1	6.1
	>16 - 17	5.2	6.3	6.1	6.3
	>17 - 18	3.9	4.2	4.2	4.3
	>18 - 19	23.2	7.2	7.5	7.1
	>19 - 20	51.4	34.6	35.3	34.5
	>20 - 21	3.5	29.4	29.0	29.6
	>21 - 22	0.0	7.1	6.2	6.9
	>22 - 23	0.0	1.0	0.9	1.0
	>23 - 24	0.0	0.1	0.1	0.1
	>24 - 25	0.0	0.0	0.0	0.0

**Table 3. Number of data points, minimum, maximum, and percent frequency distributions for the diel temperature calculations determined for the adult fish ladder sensors.**

TIME PERIOD	PARAMETER	LOCATION				
		ENTRANCE	SEC 16	EXIT 1	EXIT 2	
15 Jun–6 Oct	Statistics	Data Count	113	113	113	113
		Min (°C)	0.1	0.1	0.1	0.1
		Max (°C)	1.2	2.9	2.9	2.9
		Mean (°C)	0.4	1.2	1.2	1.2
		Median (°C)	0.4	1.1	1.0	1.1
	Frequency Distribution by Percent	Temperature Interval (°C)				
		≤0.5	65.5	14.2	14.2	14.2
		>0.5 - 1.0	32.7	31.0	34.5	31.0
		>1.0 - 1.5	1.8	33.6	30.1	31.0
		>1.5 - 2.0	0.0	10.6	8.8	13.3
		>2.0 - 2.5	0.0	8.0	8.8	8.0
		>2.5 - 3.0	0.0	2.7	3.5	2.7
		>3.0 - 3.5	0.0	0.0	0.0	0.0
		>3.5 - 4.0	0.0	0.0	0.0	0.0
		>4.0 - 4.5	0.0	0.0	0.0	0.0
1 Jul-30 Sept	Statistics	Data Count	92	92	92	92
		Min (°C)	0.1	0.3	0.3	0.3
		Max (°C)	1.2	2.9	2.9	2.9
		Mean (°C)	0.4	1.2	1.2	1.3
		Median (°C)	0.4	1.2	1.2	1.2
	Frequency Distribution by Percent	Temperature Interval (°C)				
		≤0.5	64.1	9.8	9.8	9.8
		>0.5 - 1.0	33.7	28.3	31.5	28.3
		>1.0 - 1.5	2.2	37.0	32.6	33.7
		>1.5 - 2.0	0.0	12.0	10.9	15.2
		>2.0 - 2.5	0.0	9.8	10.9	9.8
		>2.5 - 3.0	0.0	3.3	4.3	3.3
		>3.0 - 3.5	0.0	0.0	0.0	0.0
		>3.5 - 4.0	0.0	0.0	0.0	0.0
		>4.0 - 4.5	0.0	0.0	0.0	0.0

**Table 4. Number of data points, minimum, maximum, and percent frequency distributions for the hourly thermistor data recorded at the Forebay Ladder Exit string between 21 May 2011 and 18 October 2011.**

PARAMETER		APPROXIMATE DEPTH (FT)			
		20	40	60	75
Statistics	Data Count	3,612	3,612	3,612	3,612
	Min (°C)	10.5	10.6	10.6	10.5
	Max (°C)	23.9	20.7	20.2	20.3
Frequency Distribution by Percent	Temperature Interval (°C)				
	≤10	0.0	0.0	0.0	0.0
	>10 - 11	3.1	3.1	3.0	3.4
	>11 - 12	9.2	9.2	9.2	9.6
	>12 - 13	9.9	10.0	10.2	9.6
	>13 - 14	4.3	4.3	4.3	4.5
	>14 - 15	3.1	3.0	3.1	3.3
	>15 - 16	4.4	5.3	5.8	5.5
	>16 - 17	6.6	6.8	6.6	6.3
	>17 - 18	4.2	3.9	5.6	6.2
	>18 - 19	7.7	15.1	26.5	27.0
	>19 - 20	21.2	33.8	25.2	24.5
	>20 - 21	15.0	5.5	0.6	0.3
	>21 - 22	7.9	0.0	0.0	0.0
	>22 - 23	2.9	0.0	0.0	0.0
	>23 - 24	0.5	0.0	0.0	0.0
	>24 - 25	0.0	0.0	0.0	0.0

**Table 5. Number of data points, minimum, maximum, and percent frequency distributions for the hourly thermistor data recorded at the Forebay Ladder Exit string between 1 July 2011 and 30 September 2011.**

PARAMETER		APPROXIMATE DEPTH (FT)			
		20	40	60	75
Statistics	Data Count	2,208	2,208	2,208	2,208
	Min (°C)	13.7	13.7	13.7	13.7
	Max (°C)	23.9	20.7	20.2	20.3
Frequency Distribution by Percent	Temperature Interval (°C)				
	≤10	0.0	0.0	0.0	0.0
	>10 - 11	0.0	0.0	0.0	0.0
	>11 - 12	0.0	0.0	0.0	0.0
	>12 - 13	0.0	0.0	0.0	0.0
	>13 - 14	0.6	0.7	0.7	0.9
	>14 - 15	3.3	3.3	3.4	3.8
	>15 - 16	6.1	7.5	8.5	8.2
	>16 - 17	6.1	6.1	5.7	5.4
	>17 - 18	4.2	3.9	6.9	8.0
	>18 - 19	6.6	18.9	37.5	37.9
	>19 - 20	30.1	50.5	36.5	35.3
	>20 - 21	24.6	9.1	1.0	0.5
	>21 - 22	13.0	0.0	0.0	0.0
	>22 - 23	4.7	0.0	0.0	0.0
	>23 - 24	0.8	0.0	0.0	0.0
	>24 - 25	0.0	0.0	0.0	0.0

**Table 6. Number of data points, minimum, maximum, and percent frequency distributions for the hourly thermistor data recorded at the Diffuser string between 21 May 2011 and 18 October 2011.**

PARAMETER		APPROXIMATE DEPTH (FT)			
		20	40	60	75
Statistics	Data Count	3,613	3,613	3,613	3,613
	Min (°C)	10.6	10.6	10.5	10.6
	Max (°C)	23.9	21.7	20.6	20.6
Frequency Distribution by Percent	Temperature Interval (°C)				
	≤10	0.0	0.0	0.0	0.0
	>10 - 11	3.2	2.6	3.3	2.8
	>11 - 12	9.4	9.2	9.4	9.3
	>12 - 13	9.7	10.3	9.7	10.3
	>13 - 14	4.3	4.3	4.3	4.3
	>14 - 15	3.1	3.2	3.2	3.1
	>15 - 16	4.5	4.6	5.4	5.7
	>16 - 17	6.6	6.9	6.6	6.6
	>17 - 18	4.2	3.9	4.2	4.4
	>18 - 19	7.7	11.4	16.3	23.0
	>19 - 20	21.3	32.1	33.7	29.0
	>20 - 21	14.7	11.1	3.9	1.5
	>21 - 22	8.1	0.2	0.0	0.0
	>22 - 23	3.0	0.0	0.0	0.0
>23 - 24	0.3	0.0	0.0	0.0	
>24 - 25	0.05	0.0	0.0	0.0	

**Table 7. Number of data points, minimum, maximum, and percent frequency distributions for the hourly thermistor data recorded at the Diffuser string between 1 July 2011 and 30 September 2011.**

PARAMETER		APPROXIMATE DEPTH (FT)			
		20	40	60	75
Statistics	Data Count	2,308	2,308	2,308	2,308
	Min (°C)	13.8	13.8	13.7	13.8
	Max (°C)	23.9	21.7	20.6	20.6
Frequency Distribution by Percent	Temperature Interval (°C)				
	≤10	0.0	0.0	0.0	0.0
	>10 - 11	0.0	0.0	0.0	0.0
	>11 - 12	0.0	0.0	0.0	0.0
	>12 - 13	0.0	0.0	0.0	0.0
	>13 - 14	0.6	0.6	0.7	0.7
	>14 - 15	3.3	3.4	3.7	3.4
	>15 - 16	6.2	6.6	7.6	8.2
	>16 - 17	6.2	6.4	5.8	5.7
	>17 - 18	4.0	4.0	4.5	5.0
	>18 - 19	6.7	13.0	20.7	32.0
	>19 - 20	30.4	47.5	50.6	42.5
	>20 - 21	24.0	18.2	6.3	2.5
	>21 - 22	13.2	0.4	0.0	0.0
	>22 - 23	4.8	0.0	0.0	0.0
>23 - 24	0.5	0.0	0.0	0.0	
>24 - 25	0.0	0.0	0.0	0.0	

**Table 8. Number of data points, minimum, maximum, and percent frequency distributions for the hourly thermistor data recorded at the Forebay Ladder Exit 30-ft Out string between 21 May 2011 and 18 October 2011.**

PARAMETER		APPROXIMATE DEPTH (FT)				
		6.5	20	40	60	77
Statistics	Data Count	3,612	3,612	3,612	3,612	3,612
	Min (°C)	10.5	10.6	10.5	10.6	10.6
	Max (°C)	24.0	22.1	20.6	20.6	20.2
Frequency Distribution by Percent	Temperature Interval (°C)					
	≤10	0.0	0.0	0.0	0.0	0.0
	>10 - 11	3.1	2.7	3.1	2.5	3.0
	>11 - 12	9.0	9.2	9.2	9.2	9.1
	>12 - 13	10.1	10.3	10.0	10.5	10.2
	>13 - 14	4.3	4.3	4.3	4.1	4.3
	>14 - 15	3.1	3.2	3.1	3.3	3.0
	>15 - 16	4.3	4.4	5.3	5.2	5.8
	>16 - 17	6.6	6.9	6.8	6.8	6.7
	>17 - 18	4.2	4.0	4.0	4.0	5.7
	>18 - 19	7.8	9.6	15.2	22.1	26.9
	>19 - 20	21.0	30.3	33.8	29.9	24.6
	>20 - 21	15.1	14.6	5.2	2.3	0.6
	>21 - 22	8.2	0.6	0.0	0.0	0.0
	>22 - 23	2.7	0.1	0.0	0.0	0.0
	>23 - 24	0.4	0.0	0.0	0.0	0.0
	>24 - 25	0.0	0.0	0.0	0.0	0.0

**Table 9. Number of data points, minimum, maximum, and percent frequency distributions for the hourly thermistor data recorded at the Forebay Ladder Exit 30-ft out string between 1 July 2011 and 30 September 2011.**

PARAMETER		APPROXIMATE DEPTH (FT)				
		6.5	20	40	60	77
Statistics	Data Count	2,208	2,208	2,208	2,208	2,208
	Min (°C)	13.4	13.8	13.7	13.8	13.8
	Max (°C)	24.0	22.1	20.6	20.6	20.2
Frequency Distribution by Percent	Temperature Interval (°C)					
	≤10	0.0	0.0	0.0	0.0	0.0
	>10 - 11	0.0	0.0	0.0	0.0	0.0
	>11 - 12	0.0	0.0	0.0	0.0	0.0
	>12 - 13	0.0	0.0	0.0	0.0	0.0
	>13 - 14	0.6	0.6	0.7	0.5	0.7
	>14 - 15	3.2	3.4	3.4	3.5	3.4
	>15 - 16	6.0	6.3	7.6	7.7	8.5
	>16 - 17	6.3	6.6	6.1	5.9	5.8
	>17 - 18	4.0	3.7	4.1	4.4	7.1
	>18 - 19	6.7	10.1	19.0	30.5	38.4
	>19 - 20	29.8	44.4	50.7	43.7	35.3
	>20 - 21	24.7	23.9	8.5	3.8	0.9
	>21 - 22	13.4	0.9	0.0	0.0	0.0
	>22 - 23	4.5	0.1	0.0	0.0	0.0
>23 - 24	0.7	0.0	0.0	0.0	0.0	
>24 - 25	0.0	0.0	0.0	0.0	0.0	

**Table 10. Number of data points, minimum, maximum, and percent frequency distributions for the diel temperature calculations determined for the Ladder Exit string.**

TIME PERIOD	PARAMETER	APPROXIMATE DEPTH (FT)				
		20	40	60		
21 May–17 Oct	Statistics	Data Count	150	150	150	
		Min (°C)	0.1	0.1	0.1	
		Max (°C)	3.4	2.4	1.9	
		Mean (°C)	1.2	0.7	0.6	
		Median (°C)	0.9	0.7	0.6	
	Frequency Distribution by Percent	Temperature Interval (°C)	≤0.5	21.3	31.3	47.3
			>0.5 - 1.0	32.7	56.0	44.7
			>1.0 - 1.5	17.3	10.7	6.7
			>1.5 - 2.0	7.3	1.3	1.3
			>2.0 - 2.5	9.3	0.7	0.0
			>2.5 - 3.0	9.3	0.0	0.0
			>3.0 - 3.5	2.7	0.0	0.0
			>3.5 - 4.0	0.0	0.0	0.0
			>4.0 - 4.5	0.0	0.0	0.0
			1 Jul-30 Sept	Statistics	Data Count	92
Min (°C)	0.3	0.2			0.2	
Max (°C)	3.4	2.4			1.9	
Mean (°C)	1.6	0.8			0.6	
Median (°C)	1.4	0.8			0.6	
Frequency Distribution by Percent	Temperature Interval (°C)	≤0.5		8.7	17.4	39.1
		>0.5 - 1.0		27.2	65.2	48.9
		>1.0 - 1.5		18.5	14.1	9.8
		>1.5 - 2.0		10.9	2.2	2.2
		>2.0 - 2.5		15.2	1.1	0.0
		>2.5 - 3.0		15.2	0.0	0.0
		>3.0 - 3.5		4.3	0.0	0.0
		>3.5 - 4.0		0.0	0.0	0.0
		>4.0 - 4.5		0.0	0.0	0.0

**Table 11. Number of data points, minimum, maximum, and percent frequency distributions for the diel temperature calculations determined for the Diffuser string.**

TIME PERIOD	PARAMETER	APPROXIMATE DEPTH (FT)				
		20	40	60	75	
21 May–17 Oct	Statistics	Data Count	150	150	150	150
		Min (°C)	0.1	0.1	0.1	0.1
		Max (°C)	3.4	2.4	2.2	1.9
		Mean (°C)	1.2	0.8	0.7	0.6
		Median (°C)	0.9	0.7	0.6	0.6
	Frequency Distribution by Percent	Temperature Interval (°C)				
		≤0.5	24.0	28.7	32.7	46.0
		>0.5 - 1.0	32.7	48.0	54.0	48.7
		>1.0 - 1.5	14.0	17.3	11.3	4.0
		>1.5 - 2.0	8.0	2.7	1.3	1.3
		>2.0 - 2.5	11.3	3.3	0.7	0.0
		>2.5 - 3.0	7.3	0.0	0.0	0.0
		>3.0 - 3.5	2.7	0.0	0.0	0.0
		>3.5 - 4.0	0.0	0.0	0.0	0.0
		>4.0 - 4.5	0.0	0.0	0.0	0.0
1 Jul-30 Sept	Statistics	Data Count	92	92	92	92
		Min (°C)	0.2	0.2	0.2	0.2
		Max (°C)	3.4	2.4	2.2	1.9
		Mean (°C)	1.6	0.9	0.8	0.6
		Median (°C)	1.5	0.9	0.7	0.6
	Frequency Distribution by Percent	Temperature Interval (°C)				
		≤0.5	10.9	15.2	19.6	38.0
		>0.5 - 1.0	22.8	51.1	63.0	54.3
		>1.0 - 1.5	19.6	23.9	14.1	5.4
		>1.5 - 2.0	13.0	4.3	2.2	2.2
		>2.0 - 2.5	17.4	5.4	1.1	0.0
		>2.5 - 3.0	12.0	0.0	0.0	0.0
		>3.0 - 3.5	4.3	0.0	0.0	0.0
		>3.5 - 4.0	0.0	0.0	0.0	0.0
		>4.0 - 4.5	0.0	0.0	0.0	0.0

**Table 12. Number of data points, minimum, maximum, and percent frequency distributions for the diel temperature calculations determined for the Forebay Ladder Exit 30-ft Out string.**

TIME PERIOD	PARAMETER	APPROXIMATE DEPTH (FT)						
		6.5	20	40	60	75		
21 May–17 Oct	Statistics	Data Count	150	150	150	150	150	
		Min (°C)	0.1	0.1	0.1	0.1	0.1	
		Max (°C)	3.6	2.6	2.3	2.2	2.0	
		Mean (°C)	1.2	0.8	0.7	0.6	0.6	
		Median (°C)	0.9	0.7	0.6	0.6	0.5	
	Frequency Distribution by Percent	Temperature Interval (°C)	≤0.5	21.3	27.3	32.7	40.0	48.0
			>0.5 - 1.0	34.0	46.0	56.0	50.7	44.7
			>1.0 - 1.5	14.7	20.7	9.3	7.3	6.7
			>1.5 - 2.0	8.7	2.7	0.7	0.7	0.7
			>2.0 - 2.5	8.7	2.7	1.3	1.3	0.0
			>2.5 - 3.0	10.0	0.7	0.0	0.0	0.0
			>3.0 - 3.5	2.0	0.0	0.0	0.0	0.0
			>3.5 - 4.0	0.7	0.0	0.0	0.0	0.0
			>4.0 - 4.5	0.0	0.0	0.0	0.0	0.0
			1 Jul-30 Sept	Statistics	Data Count	92	92	92
Min (°C)	0.3	0.2			0.2	0.2	0.2	
Max (°C)	3.6	2.6			2.3	2.2	2.0	
Mean (°C)	1.6	1.0			0.8	0.7	0.6	
Median (°C)	1.4	0.9			0.7	0.7	0.6	
Frequency Distribution by Percent	Temperature Interval (°C)	≤0.5		8.7	13.0	19.6	30.4	40.2
		>0.5 - 1.0		27.2	47.8	64.1	55.4	48.9
		>1.0 - 1.5		17.4	29.3	13.0	10.9	9.8
		>1.5 - 2.0		12.0	4.3	1.1	1.1	1.1
		>2.0 - 2.5		14.1	4.3	2.2	2.2	0.0
		>2.5 - 3.0		16.3	1.1	0.0	0.0	0.0
		>3.0 - 3.5		3.3	0.0	0.0	0.0	0.0
		>3.5 - 4.0		1.1	0.0	0.0	0.0	0.0
		>4.0 - 4.5		0.0	0.0	0.0	0.0	0.0

**Table 13. Frequency distributions in percent for the temperature differences between the three forebay locations at four depths between 1 July and 30 September.**

DEPTH (FT)	INTERVAL (°C)	EXIT - DIFFUSER	EXIT - 30 FT OUT	DIFFUSER - 30 FT OUT
20	≤-2.0	0.0	0.0	0.0
	>-2.0 - -1.5	0.0	0.0	0.0
	>-1.5 - -1.0	0.2	0.0	0.0
	>-1.0 - -0.5	2.4	0.0	0.0
	>-0.5 - 0.0	74.0	43.0	23.6
	>0.0 - 0.5	21.6	26.2	43.2
	>0.5 - 1.0	1.3	11.0	11.8
	>1.0 - 1.5	0.3	8.4	9.3
	>1.5 - 2.0	0.2	5.8	6.2
	>2.0 - 2.5	0.1	3.4	3.6
	>2.5 - 3.0	0.0	1.7	2.0
	>3.0 - 3.5	0.0	0.5	0.3
	>3.5 - 4.0	0.0	0.0	0.0
40	≤-2.0	0.3	0.0	0.0
	>-2.0 - -1.5	0.7	0.0	0.0
	>-1.5 - -1.0	1.8	0.0	0.0
	>-1.0 - -0.5	7.9	0.1	0.0
	>-0.5 - 0.0	88.0	52.8	2.3
	>0.0 - 0.5	1.3	47.1	86.8
	>0.5 - 1.0	0.0	0.0	8.0
	>1.0 - 1.5	0.0	0.0	1.9
	>1.5 - 2.0	0.0	0.0	0.6
	>2.0 - 2.5	0.0	0.0	0.3
	>2.5 - 3.0	0.0	0.0	0.0
	>3.0 - 3.5	0.0	0.0	0.0
	>3.5 - 4.0	0.0	0.0	0.0
60	≤-2.0	0.3	0.0	0.0
	>-2.0 - -1.5	1.0	0.1	0.0
	>-1.5 - -1.0	4.0	0.8	0.0
	>-1.0 - -0.5	18.7	7.0	0.0
	>-0.5 - 0.0	49.3	92.0	60.4
	>0.0 - 0.5	26.7	0.1	30.9
	>0.5 - 1.0	0.0	0.0	7.5
	>1.0 - 1.5	0.0	0.0	0.9
	>1.5 - 2.0	0.0	0.0	0.3
	>2.0 - 2.5	0.0	0.0	0.0
	>2.5 - 3.0	0.0	0.0	0.0
	>3.0 - 3.5	0.0	0.0	0.0
	>3.5 - 4.0	0.0	0.0	0.0

**Table 13. Frequency distributions in percent for the temperature differences between the three forebay locations at four depths 1 July and 30 September (continued).**

DEPTH (FT)	INTERVAL (°C)	EXIT - DIFFUSER	EXIT - 30 FT OUT	DIFFUSER - 30 FT OUT
75 - 77	≤-2.0	0.0	0.0	0.0
	>-2.0 - -1.5	0.0	0.0	0.0
	>-1.5 - -1.0	0.0	0.0	0.0
	>-1.0 - -0.5	0.0	0.0	0.0
	>-0.5 - 0.0	27.1	39.3	82.5
	>0.0 - 0.5	64.6	52.6	17.5
	>0.5 - 1.0	7.3	7.2	0.0
	>1.0 - 1.5	0.8	0.7	0.0
	>1.5 - 2.0	0.1	0.1	0.0
	>2.0 - 2.5	0.0	0.1	0.0
	>2.5 - 3.0	0.0	0.0	0.0
	>3.0 - 3.5	0.0	0.0	0.0
	>3.5 - 4.0	0.0	0.0	0.0

**Table 14. Number of data points, minimum, maximum, and percent frequency distributions for the hourly thermistor data recorded at Unit 1 from 14 June through 6 October and 1 July through 30 September.**

PARAMETER		TIME PERIOD	
		14 JUNE – 6 OCT	1 JULY – 30 SEPT
Statistics	Data Count	2,738	2,208
	Min (°C)	11.8	13.7
	Max (°C)	19.9	19.9
Frequency Distribution by Percent	Temperature Interval (°C)		
	≤10	0.0	0.0
	>10 - 11	0.0	0.0
	>11 - 12	0.9	0.0
	>12 - 13	7.2	0.0
	>13 - 14	5.7	0.7
	>14 - 15	3.9	3.3
	>15 - 16	6.5	8.1
	>16 - 17	4.4	5.4
	>17 - 18	5.0	6.2
	>18 - 19	35.0	41.6
	>19 - 20	31.4	34.7
	>20 - 21	0.0	0.0
	>21 - 22	0.0	0.0
>22 - 23	0.0	0.0	
>23 - 24	0.0	0.0	
>24 - 25	0.0	0.0	

**Table 15. Number of data points, minimum, maximum, and percent frequency distributions for the diel temperature calculations determined for the Unit 1 thermistor from 14 June through 6 October and 1 July through 30 September.**

PARAMETER		TIME PERIOD	
		14 JUNE – 6 OCT	1 JULY – 30 SEPT
Statistics	Data Count	113	92
	Min (°C)	0.1	0.1
	Max (°C)	1.3	1.2
	Mean (°C)	0.4	0.4
	Median (°C)	0.4	0.4
Frequency Distribution by Percent	Temperature Interval (°C)		
	≤0.5	62.8	65.2
	>0.5 - 1.0	35.4	33.7
	>1.0 - 1.5	1.8	1.1
	>1.5 - 2.0	0.0	0.0
	>2.0 - 2.5	0.0	0.0
	>2.5 - 3.0	0.0	0.0
	>3.0 - 3.5	0.0	0.0
	>3.5 - 4.0	0.0	0.0
>4.0 - 4.5	0.0	0.0	