FLOODPLAIN MINING IMPACT STUDY: THERMAL INVESTIGATION

Kelly Clark - Yakima County Planning Department
Robert Raforth - Washington State Department of Ecology
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Interim Thermal Investigation Report

Overview

Small increments of temperature change can have profound impacts to biological and chemical systems. Subsequently, there are many concerns related to the influences and impacts of solar-heated water from floodplain mine ponds on anadromous fisheries in the Yakima River Basin. Water temperatures above 23.89° C (75° F) may be fatal to some species and temperatures between 15.6° C and 23.89° C (60° F and 75° F) can increase their metabolic rates and stress levels. Because increasing river temperature from floodplain mines is a central question of the study, these measurements have the highest data quality objective.

Water temperature data was collected in the Yakima River upstream, adjacent to, downstream, and within the selected floodplain mine sites. Correlating temperature measurements and plotting of the measurements over time will determine if the mine is contributing to warming of river water. Shade and flow were additional factors that need to be considered in the final analysis.

Existing and on-going temperature data collected from the East Selah and Newland sites by Central Pre-Mix personnel, as part of their independent "Thermal Transport Investigation," was used to supplement the temperature investigation for sites 4 and 6 (Selah and Newland). Therefore, this investigation corresponds with the monitoring methodologies utilized by the Central Pre-Mix thermal transport study.

Methods

Data Quality Objectives

Numeric data was collected as part of the ambient and water temperature study. Onset Optic StowAway Temp (StowAway) and Hobo® H8 Pro External Temperature (Ext) units were selected take the temperature measurements (Figures 1 and 2). All StowAway data loggers were labeled and immersed in an ice water bath of a known temperature for 15 minutes to test the calibration of the instruments. All data loggers had an offload range greater than 0 C° but less than 0.1 C°.

Figure 1. Optic StowAway temp unit

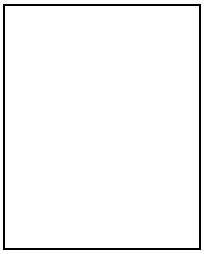

Figure 2. Hobo Ext temp unit

Each StowAway logger was then programmed to take 12 temperature measurements daily (2-hour intervals). The Ext units were also launched to collect data every two hours to allow for comparison of atmospheric and surface water temperature trends. In addition to numerically reducing bias, placement and monitoring of data loggers was used to reduce bias.

Sampling Design

The location of the monitoring stations was critical to good measurements. In general, monitoring stations were located upstream, adjacent to, downstream and in the floodplain mine. Shading from riparian vegetation and flow were also considered during data logger placement. Similarities of shading patterns, depth and flow were sought during placement of monitoring stations.

The StowAway data loggers were placed in housing constructed of perforated polyvinyl chloride pipes (PVC) and deployed in the river/pit lake. The PVC containing the data loggers was perforated with multiple holes to allow water to flow through. The pipe containing the probe will have chain attached to the cable line above the tube to lower the tube in the water column, but not enough to allow sediment accumulation within the tube that could potentially insulate the data recorders from the water flow (Figure 3). In the case of the pit lake temperature sampling, the logger were suspended by a float device or tethered to the shore (Figure 4).

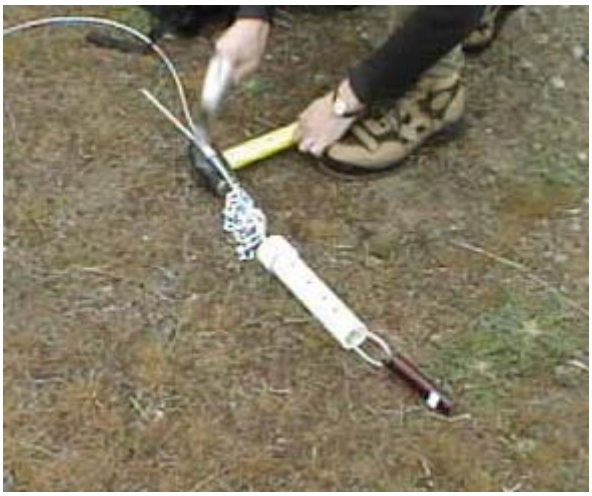

Figure 3. PVC housing.

Figure 4. Pond vertical logger string

The tube was deployed as close to the thalwag as possible and in water .3048-.6096 meters (12 – 24 inches) deep. In the case of the river temperature, data loggers where tethered to the shore with a cable (Figure 5). Air temperature loggers were located in the riparian zone of each site, which were shaded with no direct sunlight (Figure 6).

Figure 5.Optic StowAway in shaded monitoring location

Figure 6. Hobo Ext unit in riparian area.

Unfortunately, many of the sites were lacking in riparian vegetation at the desired monitoring locations. While the logger units had built in shade from the housing to protect them from direct exposure to sunlight, shading variables will be incorporated in the final analysis.

Riparian shading, water depth, and flow were considered for station placement. Each station will be provided with a shield to shade the data logger, but it will still be important to simulate shade and direct sunlight percentages of the stations. The same is true for depth and flow velocity. This is especially true for upstream and downstream stations. Deep mines will have to be evaluated for deployment depth as well.

Field Procedures

The data loggers were deployed in early April and collected data from April 15th through November 1st, 2002. The stations were checked and the data loggers were downloaded around the 15th of every month. The data loggers were downloaded using an Optical Shuttle for the Optic StowAways and a Hobo Shuttle for the Ext Temp units. Once the download process was completed, the data loggers will be re-deployed. Most sample sites were accessible from the shoreline and some of the pit lake sites were accessed with a boat. Data collected from Optical Shuttle and Hobo Shuttle was transferred to a computer at the Yakima County Planning Department, processed and backed up on the network and on compact disks.

Quality Control

Precision in the numeric value of each monitoring station was maintained by using duplicate data loggers as checks on specific monitoring stations. Additional data loggers were placed and rotated throughout each monitoring station. These additional loggers were rotated to all stations over time to ensure dedicated data loggers are within acceptable data quality objectives. Inability to gain uniformity is noted in the individual site reports.

Data Management and Review Procedures

Temperature data was downloaded in the field using the Optic Shuttle and Hobo Shuttle. The data was then transported back to the office computer and viewed with Onset software (Boxcar Pro 4.0®). Once all data was downloaded and saved on the hard drive, it was imported into MS Excel for data analysis and graphing. All data was saved to the network and backed up at Yakima County.

Data was then subject review for quality, consistency and completeness and incorporated into the cumulative data set. Furthermore, data of the replicate logger was evaluated to determine if instruments were working correctly and the precision of the measurements.

Results

Site 1: Hanson Ponds

At the Hanson Ponds site, river temperature data were recorded at an upstream site, a middle site, and a downstream site. Temperatures were also recorded in Hanson Pond 2. The upstream river station was tethered to a large tree, at a depth of approximately 2 feet and was partially shaded. The middle monitoring station was located in a smaller side channel at a depth of 2 feet and was subject to partial shading. The downstream monitoring station was located below the ponds and the City of Cle Elum's sewage

outfall pipe and directly below a connection channel from a small pond and the Yakima River. The Ext unit (air) was located in a riparian area directly below Pond 2. The period of record is from April 15 to November 14, 2002.

River

Table 1 contains the average of all temperature measurements collected in the Yakima River during each month at the upstream sample site, the middle site, and the downstream site. The table shows the difference in average temperature between the upstream sample site and the middle site; between the upstream sample site and the downstream site; and between the middle site and the downstream site. Since the comparisons are made downstream, positive values indicate an increase in downstream temperature while a negative value indicates a cooler temperature downstream.

Table 1. Average monthly river temperatures at Hanson Ponds.

	Average Monthly Upstream	**Average Monthly Middle**	**Average Monthly Downstream**	**dT Upstream to Middle**	**dT Upstream to Downstream**	**dT Middle to Downstream**
April	6.75	6.77	6.94	0.02	0.19	0.16
May	8.14	8.47	8.35	0.33	0.20	-0.12
June	9.67	9.68	9.80	0.01	0.12	0.11
July	12.00	12.03	12.13	0.03	0.13	0.10
August	14.28	14.30	14.38	0.02	0.09	0.07
September	14.89	14.91	14.99	0.02	0.10	0.08
October	10.50	10.48	10.61	-0.02	0.11	0.12
November	6.59	6.53	6.73	-0.06	0.14	0.20

Table 1 indicates that the average monthly temperature contrasts are small, but mostly showing an increasing temperature downstream. In general, a greater increase occurs between the middle sample site and the downstream site, accounting for the majority of the overall temperature increase between the upstream and downstream sites. Return flow from the sewer outfall may have contributed to this trend.

The Figure 7 time series plot shows the relation among the upstream, middle, and downstream Yakima River sample sites as reflected by the daily minimum and daily maximum temperature recorded at each site. The small spread of average monthly temperature differences shown in Table 1 are confirmed by the closely spaced data in this plot of daily minimum. As a result it is difficult to determine temperature trends or distinguish among the sites visually. To assist interpretation of the data, the same data are presented in more detail as month by month plots over the period of record (Appendix I).

Strong temperature gradients are present in the data, including the “flip-flop” occurrence in early September, which could be due to releases from upstream regulating reservoirs or by changes in air temperature. Air temperature data was measured at each site at the same frequency as river and pond temperatures and the relationship was easily investigated (Figure 7).

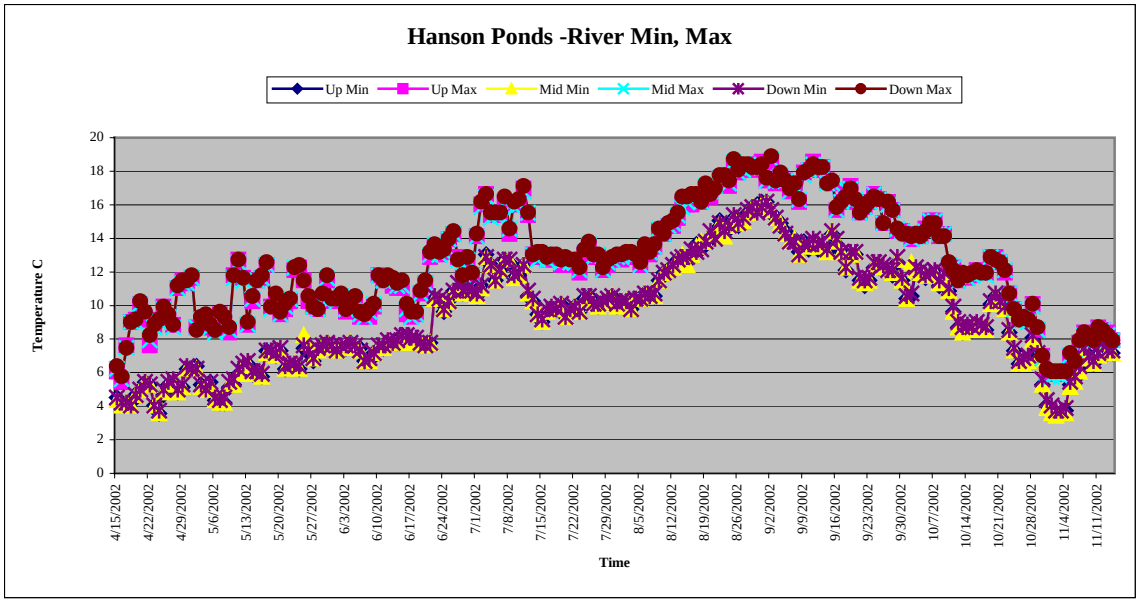

Figure 7. River minimum and maximum at Hanson Ponds.

Figure 8 adds the maximum daily air temperature to the previous time series plot of minimum and maximum daily temperatures. For clarity, the minimum daily temperature has been omitted as redundant. Inspection of the plot suggests a correlation between air and river temperatures, although monthly divergences are apparent. Also apparent is the peaking of air temperature a month or more ahead of peak river temperatures and the cold weather that occurred in early November.

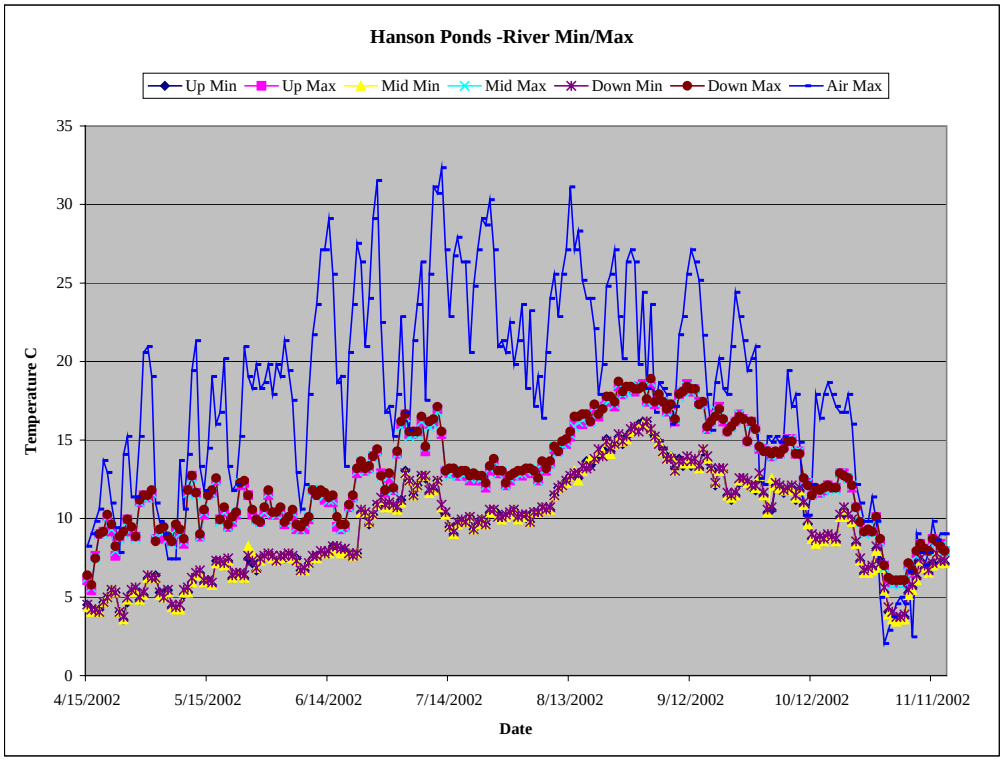

Figure 8. River minimum and maximum, plus air temperature at Hanson Ponds.

As a further investigation into the relationship between air temperature and river temperature, some correlation coefficients were calculated. Table 2 shows the calculated relationship between monthly minimum and maximum upstream river and air temperatures. Inspection of the table shows that the best correlation between river and air temperature occurred early in the period of record and again late in the season. The months of July and August had the poorest correlation. The July minimum, and to a lesser extent the maximum, correlation was apparently influenced by unusual data.

Table 2. River temperature correlation coefficients at Hanson Ponds.

Year 2002	**Minimum Daily (C°)**	**Maximum Daily (C°)**
April	0.772	0.820
May	0.907	0.695
June	0.683	0.679
July	-0.425	-0.006
August	0.506	0.319
September	0.707	0.649
October	0.901	0.802
November	0.992	0.886

Pond

The data in the Figure 9 time series plot represents the daily minimum and maximum temperatures measured as a vertical profile in Hanson Pond 2. Temperature measurements were recorded at a depth of 2 feet, 6 feet, and 10 feet below the surface. The period of record is from April 15 to November 1, 2002.

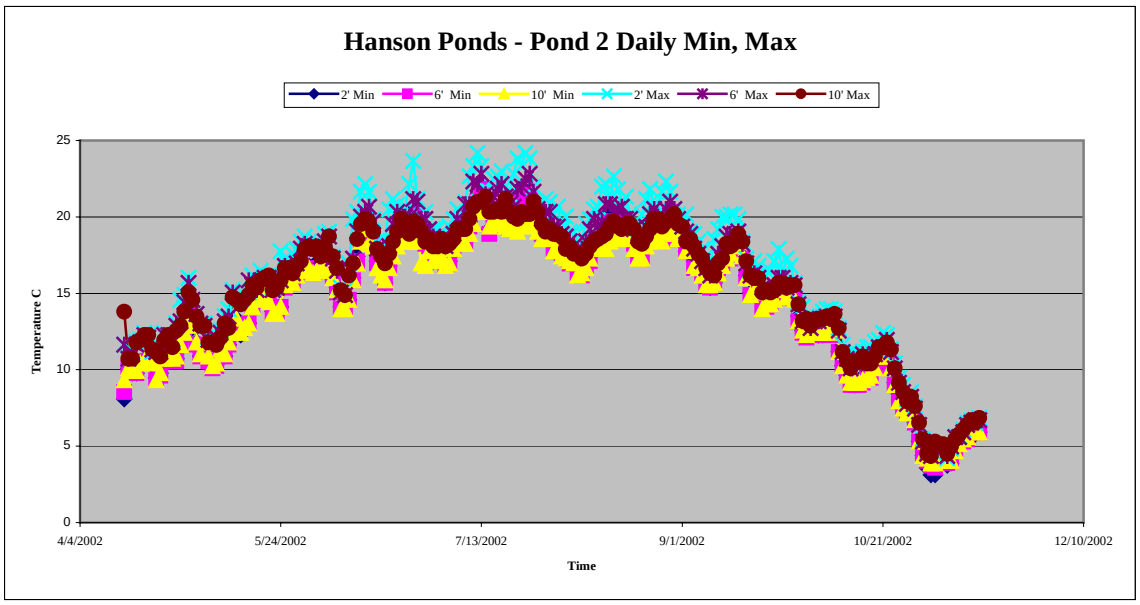

Figure 9. Hanson Pond 2 daily minimum and maximum.

This plot shows heating of the upper 2 feet of the water column, as shown by the 2 foot maximum temperature curve which systematically represents the highest maximum daily temperature. The heating is most pronounced during the early summer to early fall time period. Most of the temperature values occur in a tight spread on a daily basis with little difference between maximum and minimum temperature or among the depths of measurement. However, in late June, as the temperature at a depth of 10 feet approaches 18 ^{o}C to 19 ^{o}C it shows a tendency to diverge from the shallower measurements. This may reflect the cooling influence of ground water recharge.

Site 2: Gladmar

Temperature monitoring locations were located upstream of the former pit site, in the middle, and at the downstream portion of the breached pond. The upstream monitoring location was attached to a large rip-rap dike in relatively deep, swift water; the middle monitoring station was located off the east bank of the former pit site and was exposed to direct sunlight, siltation, and some low flow problems. It was subsequently moved to the west bank in mid-September. The downstream monitoring location was located in relatively deep water and experienced partial shading. The Ext unit (air) was located in a riparian area in the downstream portion of the site. Temperature data were recorded beginning April 15 and ending November 14, 2002.

River

Table 3 contains the average of all temperature measurements collected in the Yakima River during each month at the upstream sample site and the downstream site. Data from a middle site have been omitted due to erratic results probably related to rise and fall of the water depth at the site. The table also shows the difference in average temperature between the upstream sample site and the downstream site. Comparisons are made downstream. Thus, a positive value indicates an increase in downstream temperature while a negative value indicates a cooler temperature downstream. The table indicates that the average monthly temperature contrasts are small, but mostly show an increasing temperature from upstream to downstream.

Table 3. Average monthly river temperature at Gladmar.

	Average Upstream	**Average Downstream**	**dT Upstream/ Downstream**
April	7.24	7.31	0.07
May	8.95	9.07	0.12
June	10.98	11.10	0.11
July	13.59	13.77	0.19
August	15.05	15.12	0.07
September	15.31	15.34	0.03
October	10.02	10.03	0.00
November	5.65	5.56	-0.09

Figure 10 shows the daily minimum and maximum temperatures recorded at the upstream and downstream sites. Inspection of the plot indicates that there is a small but persistent increase in the temperature of the river downstream from the upstream site. This increase is reflected in both the daily minimum and the daily maximum temperatures. More detail can be observed in the monthly time series plots of daily minimum and maximum temperatures in Appendix I.

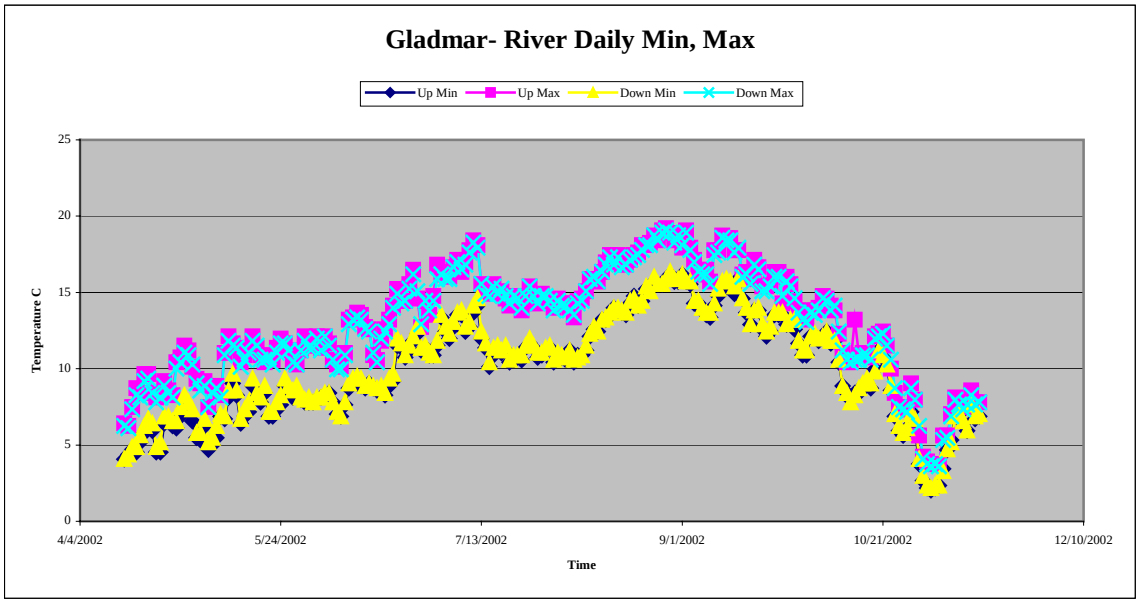

Figure 10. River minimum and maximum at Gladmar.

Site 3: I-90 Ponds

The upstream and middle temperature monitoring locations were both located upstream of Pond 4, but the middle station was central to the pond complex. Both the upstream and downstream locations were partially shaded and situated under approximately 2-3 feet of surface water. The downstream station was located directly below Pond 4, was partially shaded and situated in 2 to 3 feet of water.

In addition, two monitoring station were tethered to the pond shoreline at a depth of 2 to 3 feet (pond water levels fluctuated with river level) on the west bank of the pond (nearest to the freeway) in early June. The Ext (air) unit was located in the riparian area near the upstream river monitoring location. Temperature data for the Ext and river monitoring locations were recorded from April 15 to November 14, 2002.

River

Table 4 shows the average of the temperature data recorded each month and the change in average temperature between the upstream sample site and the middle sample site; between the upstream site and the downstream site; and between the middle site and the downstream site. Positive numbers represent an increase in temperature in the downstream direction while negative values represent cooler downstream temperatures.

The table documents a consistent and perhaps significant increase in temperature among the sample sites. The greatest temperature increases occur between the middle site and the downstream site, with over 1 ^{o}C increase in October.

Table 4. Average monthly river temperature at I-90 Pond 4.

	Average Upstream	**Average Middle**	**Average Downstream**	**dT Upstream/Middle**	**dT Upstream/ Downstream**	**dT Middle/ Downstream**
April	7.36	7.36	7.71	0.00	0.35	0.35
May	8.99	9.03	9.37	0.04	0.38	0.34
June	11.00	11.03	11.31	0.02	0.30	0.28
July	13.66	13.68	14.05	0.02	0.39	0.37
August	15.05	15.06	15.28	0.02	0.24	0.22
September	15.28	15.29	15.69	0.01	0.41	0.40
October	10.07	10.22	11.24	0.15	1.17	1.02
November	5.65	5.75	6.54	0.10	0.90	0.79

Figure 11 displays the river daily minimum and maximum temperature time series and suggests little difference among the maximum temperatures at the various measurement sites early in the period of record. However, during the mid-summer and fall the river temperature notably increases in the downstream direction. The minimum temperatures appear to retain the same relationship throughout the year, with the downstream minimum temperature slightly higher than the other two sites.

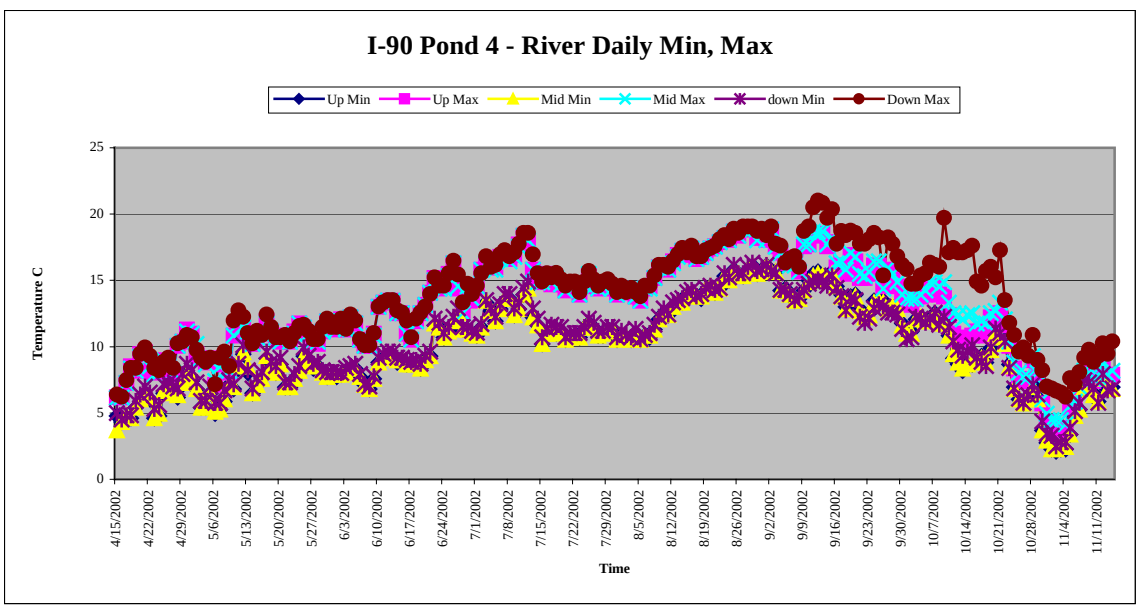

Figure 11. Daily river minimum and maximum at I-90 Pond 4.

Pond

The Figure 12 time series plot represents the minimum and maximum daily vertical temperature gradient measured at Pond 4. Pond temperatures were recorded near the shoreline at depths of 3 feet.

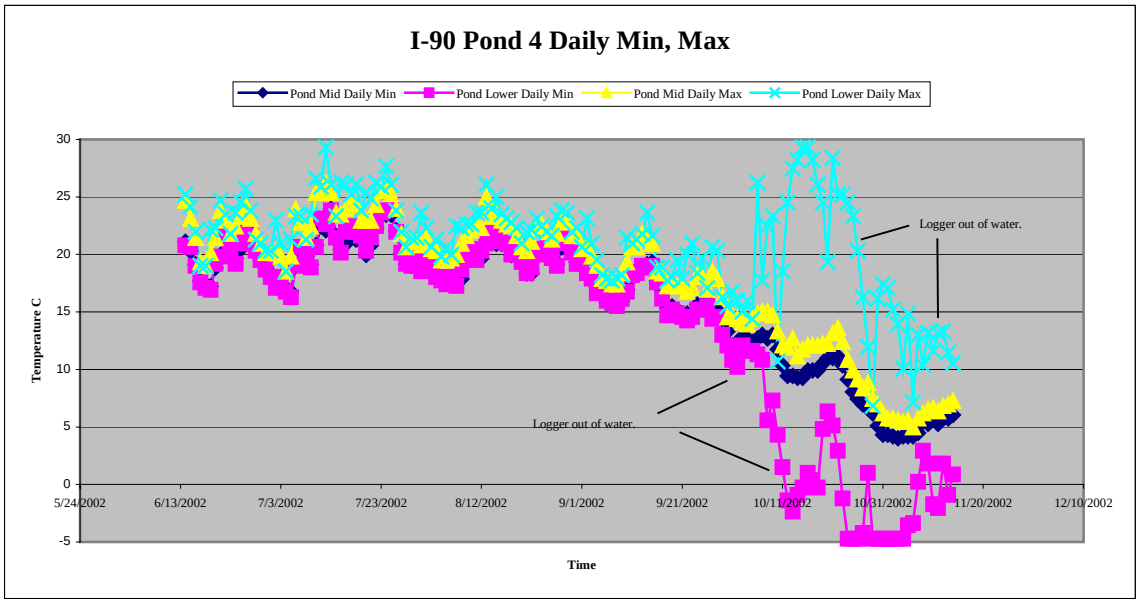

Figure 12. Daily minimum and maximum at I-90 Pond 4.

Site 4: Selah Ponds

All of the river and pond data was collected by Central Pre-Mix, as part of their thermal investigation of East Selah Ponds. The upstream and middle monitoring locations were located upstream and adjacent to Pond 1 at a depth of 3 to 5 feet off the riprap dike on the east bank of the river; shading was very minimal. Downstream locations were partially shaded and situated under approximately 2-3 feet of flow. The French Drain station was also incorporated into the dataset.

Pond 1 vertical stringer was located in the center of Pond 1 at depths of 2, 6, 12, 24, and 32.2 feet. The Ext (air) unit was located in the riparian area near the lower eastern portion of Pond 1. Temperature data for the Ext and river monitoring locations were recorded from April 15 to November 1, 2002.

River

Table 5 is the average of all river temperature data measurements each month at the upstream sample site, the middle site, and the downstream site. Table 6 shows the difference in average temperature between the successive upstream sample site and the next downstream site. The comparisons are made downstream. As a result, a positive value indicates an increase in downstream temperature while a negative value indicates a cooler temperature downstream.

Table 5. Average monthly river temperature at Selah Ponds.

	Average 2L	**Average 5L**	**Average 6L**	**Average 8L**	**Average 100A**
April	9.34	9.40	9.00	10.82	8.68
May	11.85	11.96	11.54	11.99	11.83
June	13.48	13.52	13.08	13.51	13.48
July	16.85	16.88	16.43	16.92	17.17
August	15.82	16.88	16.39	16.88	17.04
September	14.28	16.21	15.79	16.36	19.86
October	9.50	10.30	9.90	10.35	14.42

Table 6. Change in average monthly river temperature at Selah Ponds.

	dT 2L/5L	**dT 5L/6L**	**dT 6L/8L**	**dT 8L/100A**	**dT 2L/100A**
Apr	0.05	-0.39	1.81	-2.14	-0.67
May	0.11	-0.42	0.45	-0.17	-0.02
June	0.04	-0.44	0.43	-0.03	0.00
July	0.02	-0.44	0.49	0.24	0.31
August	1.05	-0.48	0.48	0.16	1.21
September	1.93	-0.42	0.57	3.51	5.58
October	0.80	-0.41	0.45	4.07	4.91

Table 6 indicates that the average monthly temperature contrasts are inconsistent. Between many stations, monthly temperature increases occur, while other months cooling occurs. However, Table 6 mostly shows an increase in temperature downstream, especially during the summer and early fall.

Figure 13 shows the daily minimum and maximum temperatures for the five river sites. The plot illustrates the slight but persistent increase in downstream temperature among the sample sites. For the most part, slight separation among the data is indicated until early in the fall. At that time, the furthest downstream sites record large temperature increases in both minimum and maximum daily temperatures.

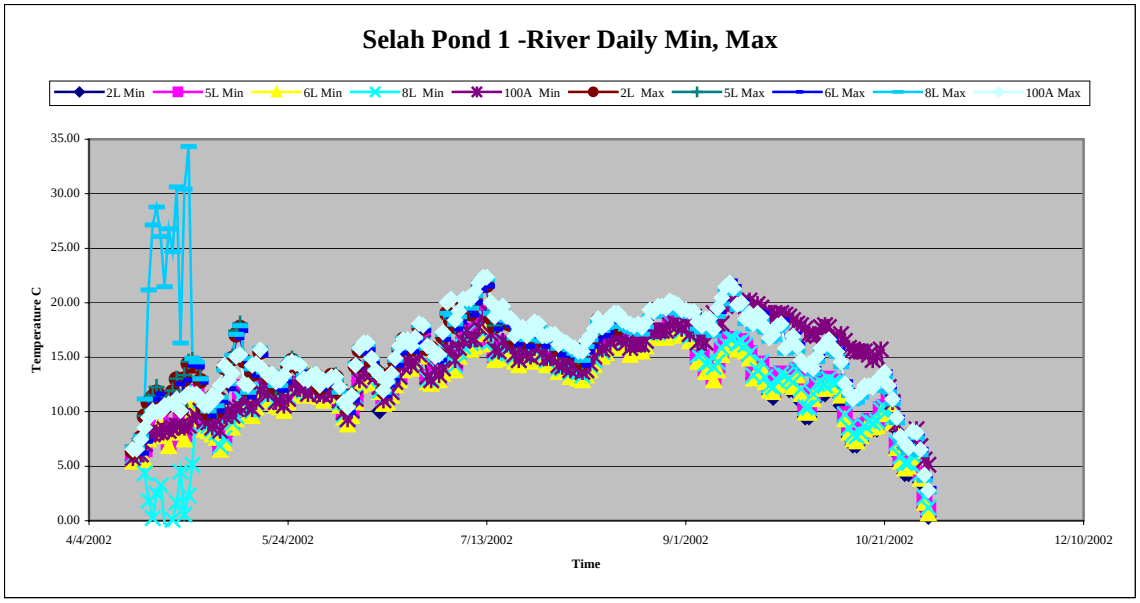

Figure 13. Daily river minimum and maximum at Selah.

Pond

Most of the data were lost from the vertical profile samplers during the late spring and throughout the summer (Figure 14). Stratification of the pond is evident in the spring. Likewise, pond turnover was apparently captured in early September, as shown by the convergence of the data.

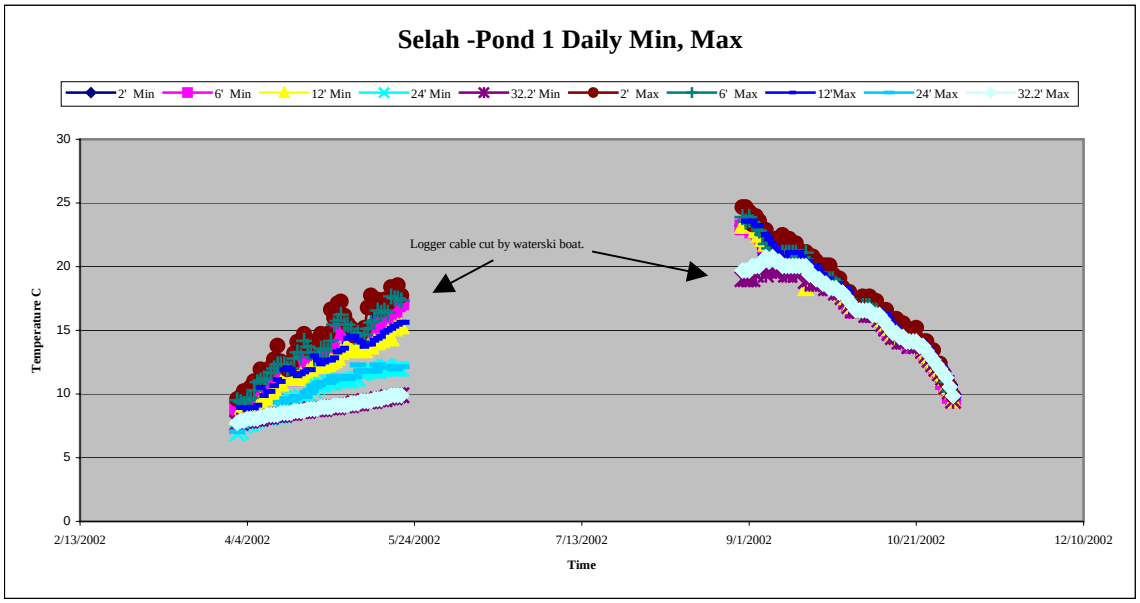

Figure 14. Daily minimum and maximum for Selah Pond 1.

Site 5: Terrace Heights

The Terrace Heights site is an avulsed pit site. At the Terrace Heights site, temperature data were recorded beginning April 15 and ending November 14, 2002. Data were obtained at an upstream site, a middle site, and a downstream site in the Yakima River. All monitoring locations were placed within the former pit area.

Table 7 shows the average of the temperature data recorded each month and the change in average temperature between the upstream sample site and the middle sample site; between the upstream site and the downstream site; and between the middle site and the downstream site. Positive numbers represent an increase in temperature in the downstream direction while negative values represent cooler downstream temperatures.

Table 7. Average monthly river temperature for the Terrace Heights site.

	Average Upstream	**Average Middle**	**Average Downstream**	**dT Upstream/Middle**	**dT Upstream/ Downstream**	**dT Middle/ Downstream**
April	8.22	8.50	8.71	0.28	0.49	0.21
May	10.39	10.61	10.54	0.22	0.15	-0.07
June	13.00	12.26	13.13	-0.74	0.13	0.87
July	17.20	16.50	17.42	-0.70	0.22	0.92
August	17.55	18.05	17.83	0.50	0.28	-0.22
September	16.07	16.70	16.43	0.62	0.36	-0.27
October	10.90	11.60	11.61	0.70	0.71	0.01
November	5.27	6.75	6.39	1.48	1.12	-0.36

Table 7 indicates a generally small increase in temperature downstream among the sample sites. The increase is not consistent, and also varies in occurrence between the sample sites, with a slight tendency for a greater increase between the upstream site and the middle site. Flip-flop may have had an influence on temperatures at the Terrace Heights site and potentially further down the Yakima River in September and October due to the release of cold water from Rimrock Reservoir.

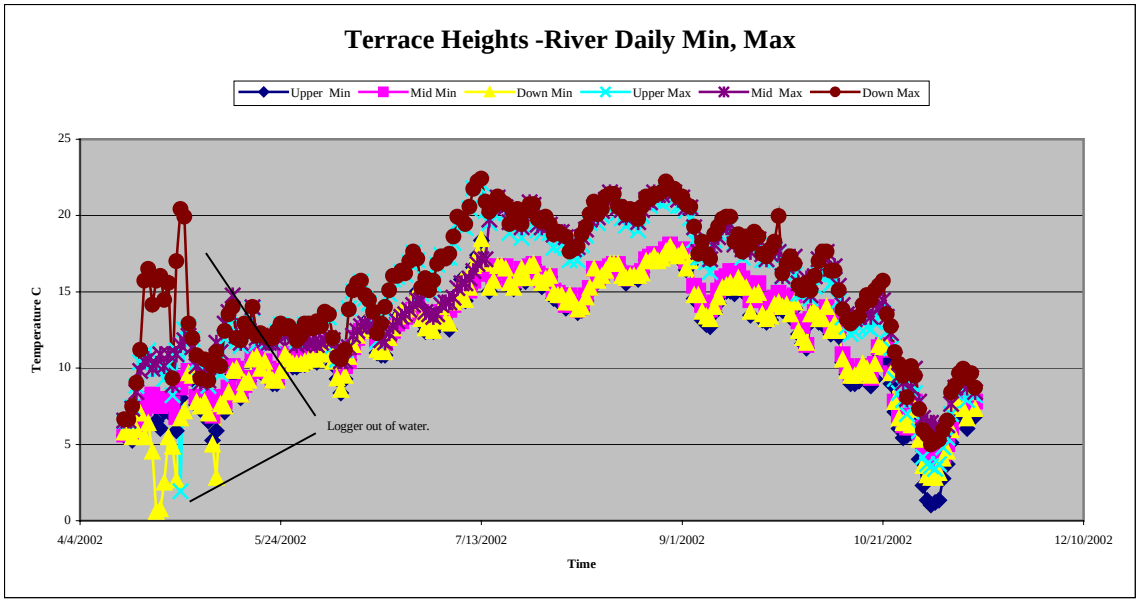

Figure 15. Daily minimum and maximum for Terrace Heights.

Figure 15 shows the minimum daily and maximum daily temperatures at the Terrace Heights site. The plot suggests little difference among the maximum temperatures at the various measurement sites early in the period of record. However, during the mid-summer the maximum river temperatures at the upstream and downstream sites notably increase, while the middle site reflects lower temperatures, possibly to due its location directly below a spring brook, and or from insulation from siltation after receded high flows. The minimum temperatures appear to retain the same relationship throughout the year, with the downstream minimum temperature slightly higher than the other two sites.

Site 6: Newland

River and pond temperature data was monitored and collected by Central Pre-Mix personnel. The upstream and downstream monitoring locations were tethered to the riprap dike on the east bank of the Yakima River; depths of the stations were approximately 3 feet and shading was minimal.

Pond 1 vertical stringer was located in the center of Pond 1 at depths of 2, 6, 12, and 21.5 feet. The Ext (air) unit was located in the riparian area below Pond 1 on the dike. Temperature data for the Ext and river monitoring locations were recorded from April 15 to November 1, 2002.

River

Table 8 shows the average of the temperature data recorded each month and the change in average temperature between the upstream sample site and the downstream site. Positive numbers represent an increase in temperature in the downstream direction while negative values represent cooler downstream temperatures. Table 8 indicates that there is little change in the river temperature at this site. In general, there is a small decrease in

temperature downstream among the sample sites. The decrease is not consistent, and also varies by month.

Table 8. Average monthly river temperature at Newland.

	Average Upstream	**Average Downstream**	**dT Upstream/ Downstream**
April	8.17	8.38	0.20
May	10.55	10.57	0.02
June	13.13	13.02	-0.11
July	17.32	17.02	-0.30
August	17.46	17.29	-0.17
September	16.18	16.09	-0.09
October	11.06	10.99	-0.07

The data in this time series plot represent the daily minimum and maximum temperatures in the river at the site (Figure 16). The plot indicates that the upstream daily minimum and maximum temperatures are higher than the downstream temperatures. This could be related to the locations selected for the temperature recorders and the distance of the pond from the river.

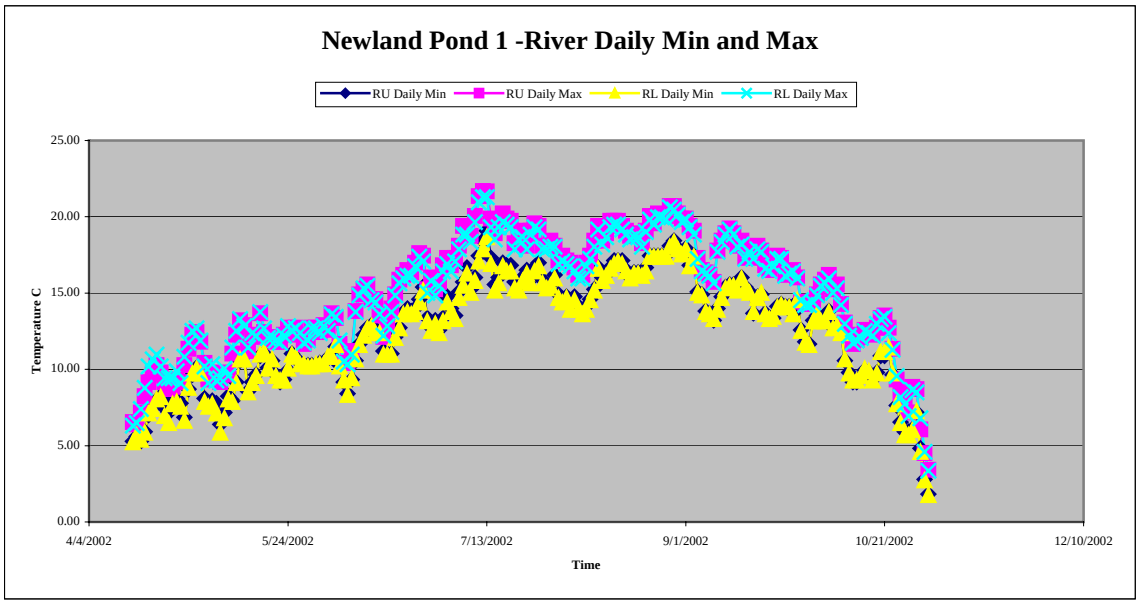

Figure 16. River daily minimum and maximum at Newland.

Pond

Figure 17 shows minimum and maximum temperature data recorded in a vertical profile in Newland Pond. Temperature data from the 2 foot depth is notable hotter early in the year than from the other depths. However, by summer, most of the data were closely spaced. The pond was actively used as a settling pond during this time, which apparently resulted in burying the deepest temperature recorder and also kept the pond from stratifying.

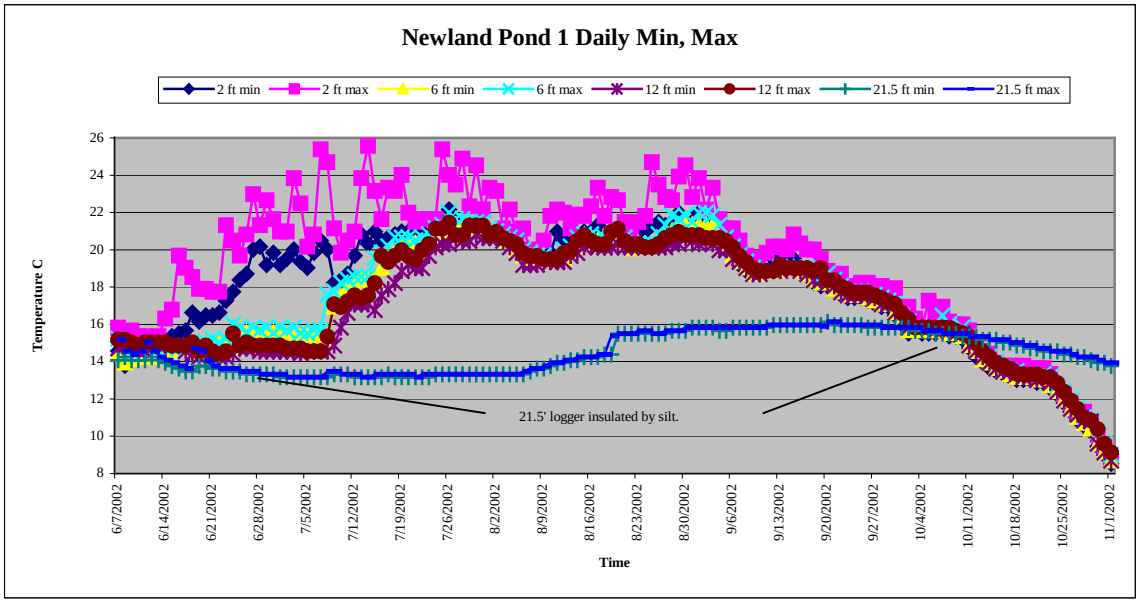

Figure 17. Daily minimum and maximum for Newland Pond 1.

Site 7: Edler Ponds

The upstream, middle, and downstream monitoring locations were located on the west bank of the river on a smaller side channel adjacent to the site. All monitoring locations were tethered to the shore, were subject to riparian shading and were situated under approximately 2-3 feet of surface flow.

Ponds 1 and 3 contained vertical stringers, but were lost to vandalism over the 4th of July weekend. The dataset was not sufficient to incorporate into the report. The Ext (air) unit was located in the riparian area near the lower eastern portion of Pond 2 (Figure 110). Temperature data for the Ext and river monitoring locations were recorded from April 15 to November 1, 2002.

River

Table 9 shows the average of the temperature data recorded each month and the change in average temperature between the upstream sample site and the middle sample site; between the upstream site and the downstream site; and between the middle site and the downstream site. Positive numbers represent an increase in temperature in the

downstream direction while negative values represent cooler downstream temperatures. The results in Table 9 indicate a generally inconsistent pattern of hotter and cooler temperatures among the sample sites. Small increases and decreases in temperature among the sample sites are evident and vary month by month.

Table 9. Average monthly river temperature at Edler Ponds.

	Average Upstream	Average Middle	Average Downstream	dT Upstream/Middle	dT Upsteam/ Downstream	dT Middle/ Downstream
April		8.73				
May	11.53	11.46	11.63	-0.07	0.10	0.17
June	13.21	13.24	13.30	0.03	0.09	0.06
July	18.09	17.78	17.22	-0.31	-0.87	-0.56
August	18.14	17.83	17.46	-0.31	-0.68	-0.37
September	16.52	16.46	16.20	-0.05	-0.32	-0.27
October	11.99	12.73	13.25	0.75	1.27	0.52
November	6.79	8.60		1.81		

The Edler Ponds time series plot of maximum and minimum daily river temperatures shows the variation in heating and cooling among the sample sites (Figure 18). During the summer months, it appears that the downstream maximum temperatures stand out as significantly warmer than the other sites.

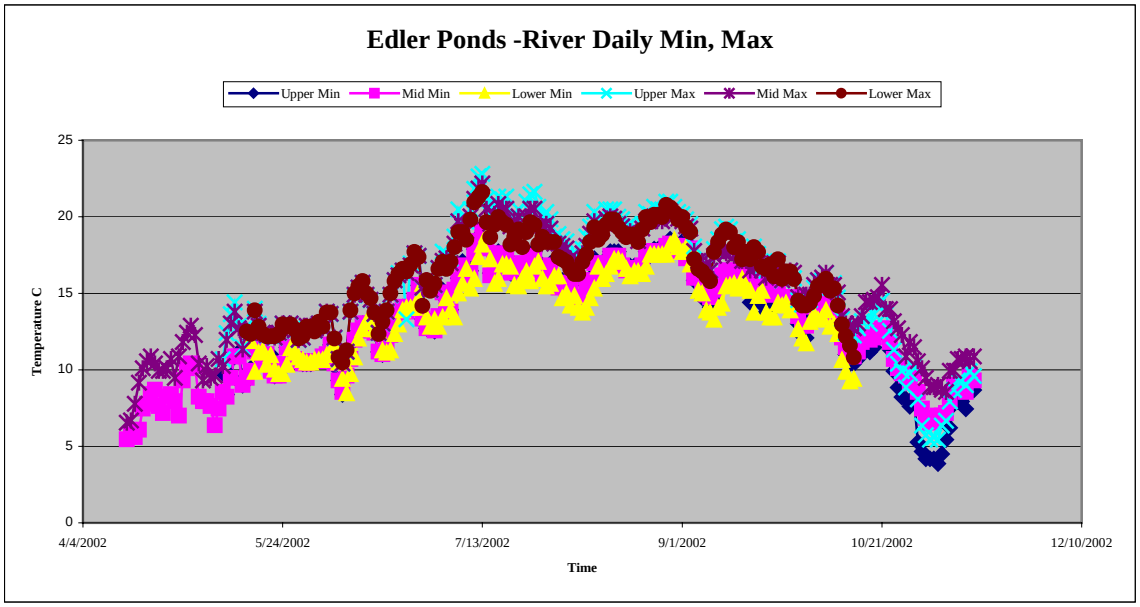

Figure 18. River daily minimum and maximum for Edler Ponds.

Site 8: Parker

Parker is an avulsed pit site in which multiple ponds are connected to the Yakima River. The upstream river monitoring location was tethered to a vegetated dike along the

northwest portion of the site (along a relatively large side channel). The middle monitoring location was situated in one of the central ponds in approximately 2 to 3 feet of water. This station was exposed to direct sunlight and experienced periods of siltation. The downstream station was located near the mouth of the lowest pond, near the outlet of the connected ponds to the Yakima River. The downstream location was partially shaded and was situated under 3 feet of water.

The Ext (air) unit was located in the riparian area near the upper portion of the site near the upstream monitoring station. Temperature data for the Ext and river monitoring locations were recorded from April 15 to November 1, 2002.

River

Table 10 shows the average of the temperature data recorded each month and the change in average temperature between the upstream sample site and the middle sample site; between the upstream site and the downstream site; and between the middle site and the downstream site. Positive numbers represent an increase in temperature in the downstream direction while negative values represent cooler downstream temperatures. Table 10 indicates a substantial increase in temperature downstream between the upper and middle sample sites. The increase from the middle sample site to the downstream site is not consistent, and also varies monthly from warmer to cooler.

Table 10. Average monthly river temperature at Parker.

	Average Upstream	**Average Middle**	**Average Downstream**	**dT Upstream/ Middle**	**dT Upstream/ Downstream**	**dT Middle/ Downstream**
April	8.76	9.62	9.73	0.86	0.98	0.11
May	11.02	13.22	11.38	2.20	0.36	-1.84
June	13.42	13.74	13.54	0.32	0.12	-0.20
July	17.60	19.27	19.36	1.68	1.77	0.09
August	17.68	19.10	19.02	1.42	1.34	-0.08
September	16.21	17.06	17.31	0.85	1.10	0.26
October	10.93	11.62	11.93	0.69	1.00	0.31
November	5.45	6.06	5.58	0.61	0.12	-0.49

Figure 19 shows the daily minimum and maximum temperatures recorded at the three sample sites. The plot demonstrates the increase in temperature downstream across the site. In particular, the temperature increase between the upstream site and the middle site is evident in both the minimum and maximum temperature data.

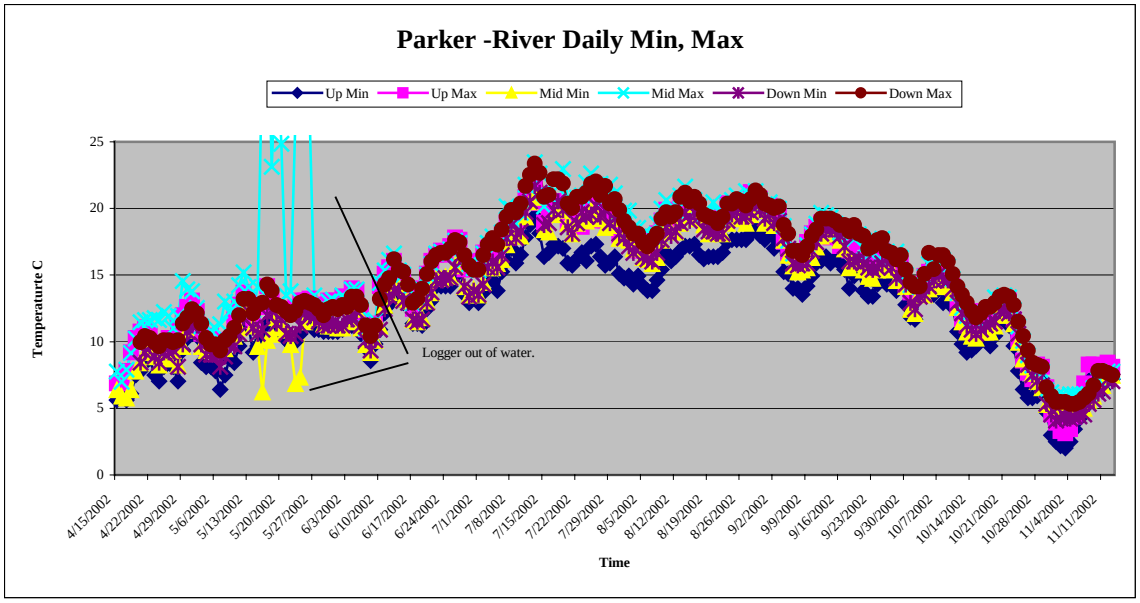

Figure 19. River Daily minimum and maximum for Parker.

Site 9: I-82 Ponds

The upstream, middle, and downstream monitoring locations were located on the west bank of the river on smaller side channels adjacent to the site (smaller meaning relative to the expansive morphology of the Wapato reach). All monitoring locations were tethered to the shore, were subject to riparian shading and were situated under approximately 2-3 feet of surface flow. The downstream monitoring station was located on a side channel that is seasonally connected at the upstream end during the spring and early summer and maintained flow throughout mid summer and fall via interstial flow.

Pond 5 contained a vertical stringer and collected temperature data at 2, 6,10, and 14 foot depths. The Ext (air) unit was located in the riparian area near the upstream river station of the site. Temperature data for the Ext and river monitoring locations were recorded from April 15 to November 1, 2002. Pond data was collected from June 27 to November 1, 2002

River

Table 11 contains the average of all temperature measurements collected in the Yakima River during each month at the upstream sample site, the middle site, and the downstream site. The table shows the difference in average temperature between the upstream sample site and the middle site; between the upstream sample site and the downstream site; and between the middle site and the downstream site. Since the comparisons are made downstream, positive values indicate an increase in downstream temperature while a negative value indicates a cooler temperature downstream.

Table 11. Average monthly river temperature at I-82 Ponds 4&5.

	Average Monthly Upstream	Average Monthly Middle	Average Monthly Downstream	dT Upstream to Middle	dT Upstream to Downstream	dT Middle to Downstream
April	9.34		8.83		-0.51	
May	11.77	12.41	12.11	0.63	0.33	-0.30
June	14.10	13.94	14.22	-0.15	0.13	0.28
July	20.45	18.53	16.70	-1.92	-3.75	-1.83
August	18.91	17.65	16.46	-1.26	-2.44	-1.19
September	16.98	16.65	16.47	-0.33	-0.51	-0.18
October	11.53	12.20	12.30	0.67	0.78	0.10
November	5.87	5.68	5.61	-0.19	-0.26	-0.07

The data in Table 11 show that this site is unique among those sites included in this investigation in that during most months there is cooling between the upstream and the downstream sample sites. The temperature gradient is also substantially greater across Site 9 than any of the other sites. The temperature changes appear to be evenly distributed between the upstream sample site and the middle site, and between the middle sample site and the downstream site (Figure 20).

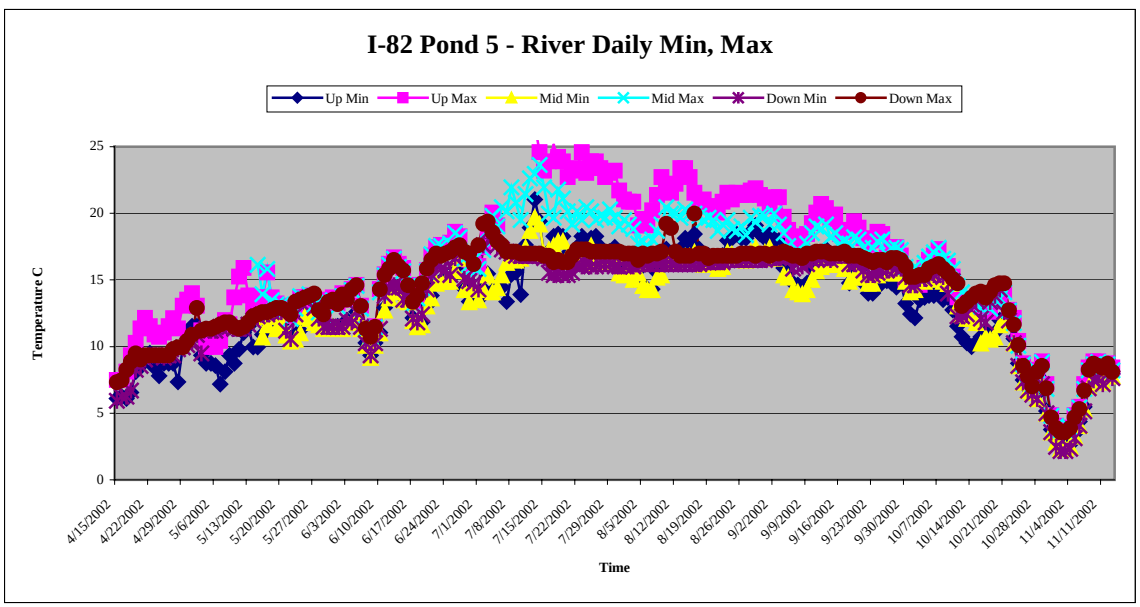

Figure 20. River daily minimum and maximum for I-82 Pond 5.

Pond

Figure 21 represents a vertical profile of daily minimum and maximum temperatures in Pond 5. Temperature stratification occurred during the summer and turnover occurred in early September.

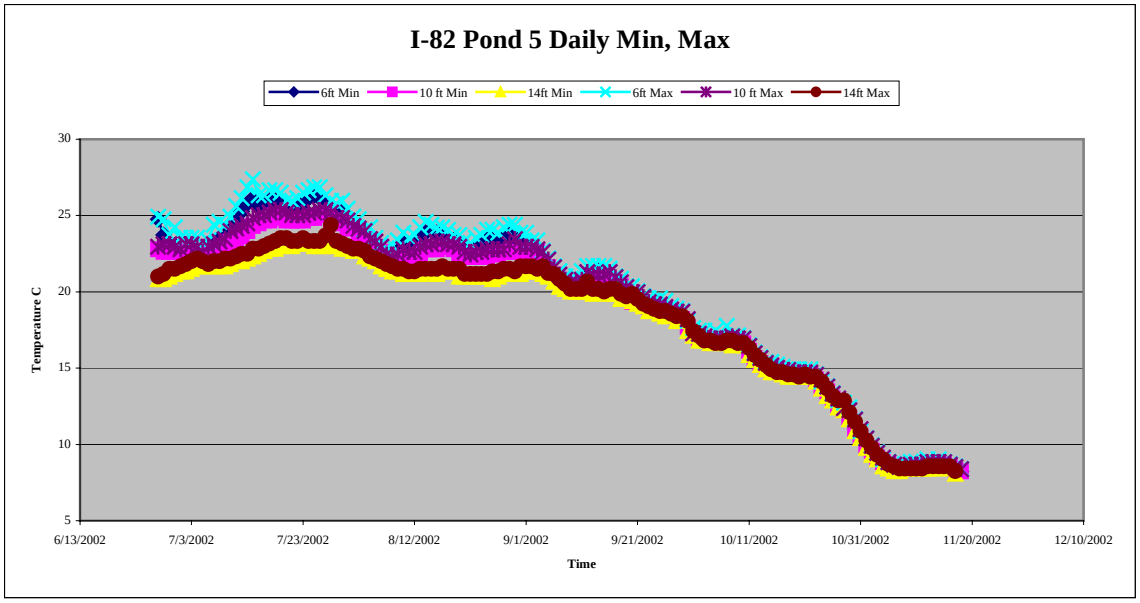

Figure 21. Daily minimum and maximum for I-82 Pond 5.

Site 10: DeAtley

The upstream, middle, and downstream monitoring locations were tethered to the shore, were subject to riparian shading and were situated under approximately 2-3 feet of surface flow. Flow fluctuated dramatically throughout the period of record and vandalism impacted the middle and downstream monitoring locations on numerous occasions. The upstream monitoring station was not subject to vandalism, but experienced a period of low flow in the fall. The middle location was situated below the City of Richland's sewer treatment outfall, and the lower monitoring station was situated below the pump outfall of the active mining site.

Pond data was recorded on a vertical stringer at depths of 2, 6, and 10 feet. The Ext (air) unit was located in the riparian area near the lower eastern portion of Pond 2. Temperature data for the Ext, pond, and river monitoring locations were recorded from April 15 to November 1, 2002.

River

Table 12 shows the average of the temperature data recorded the two months of record and the change in average temperature between the upstream sample site and the middle sample site; between the upstream site and the downstream site; and between the middle site and the downstream site. Positive numbers represent an increase in temperature in the downstream direction while negative values represent cooler downstream temperatures. Table 12 indicates a generally small increase in temperature downstream among the sample sites.

Table 12. Average monthly river temperature at DeAtley Pond.

	Average Upstream	Average Middle	Average Downstream	dT Upstream/Middle	dT Upstream/ Downstream	dT Middle/ Downstream
April	12.29	11.80	12.34	-0.49	0.05	0.54
May	15.69	16.02	15.56	0.33	-0.12	-0.45
June	17.90	18.36	15.72	0.46	-2.18	-2.64
July	23.34	23.55		0.21		

The Figure 22 time series plot shows the minimum daily and maximum daily river temperatures at the site. The plot suggests little consistent difference among the maximum temperatures at the various measurement sites early in the period of record. During the mid-summer the downstream sample site was offline and during the early period of record and the late period of record, the middle recorder was out of the water. It appears that through the summer, the middle site recorded slightly higher river temperatures than the upstream site.

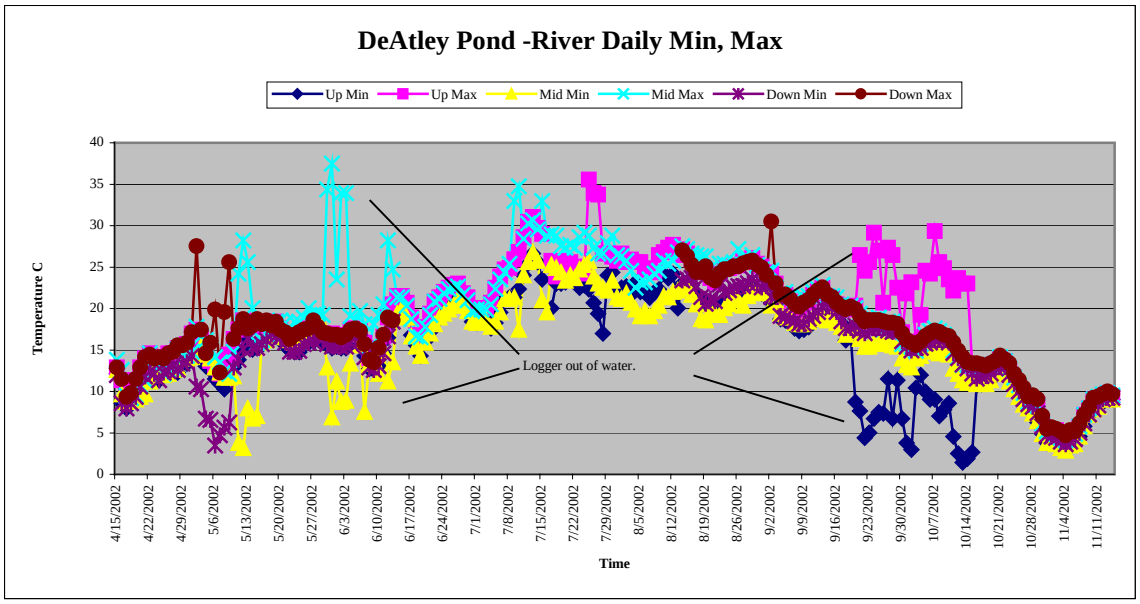

Figure 22. River daily minimum and maximum at DeAtley Pond.

Pond

This time series plot of the DeAtley Pond represents a vertical profile of daily minimum and maximum temperatures in the pond (Figure 23). Clear evidence for temperature stratification occurs during the summer and turnover occurred in mid September.

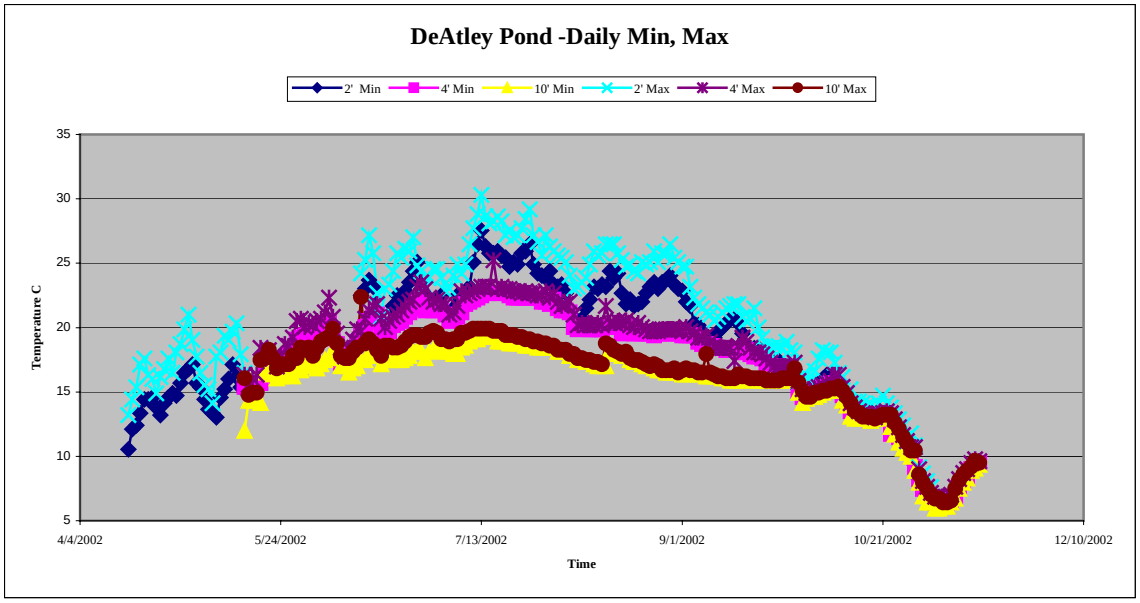

Figure 23. Daily minimum and maximum for DeAtley Pit.

Summary

River

In summary, temperatures increased incrementally from the upper to lower Yakima River. Within the study area, three distinct site groupings were identified by thermal breaks; the upper grouping includes sites 1-3 (Hanson Ponds, Gladmar, and I-90 Pond 4), the middle grouping includes sites 4-8 (Selah Ponds, Terrace Heights, Newland, Edler Ponds, and Parker Ponds), and the lower grouping includes sites 9-10 (I-82 Ponds 4&5 and DeAtley Pond) (Figure 24).

The month of November was the coolest month for all river sites. The temperature difference between September and October and October to November is a dramatic trend reflected in all sites (Figure 25). Due to flow regulation practices, ground water influences, irrigation diversions, shading characteristics, channel geomorphology and climatic variables, April through October were variable between site groupings and individual sites. However, the depth, shading, flow, and other site-specific attributes at the monitoring stations of each site must be reviewed and considered in further detail.

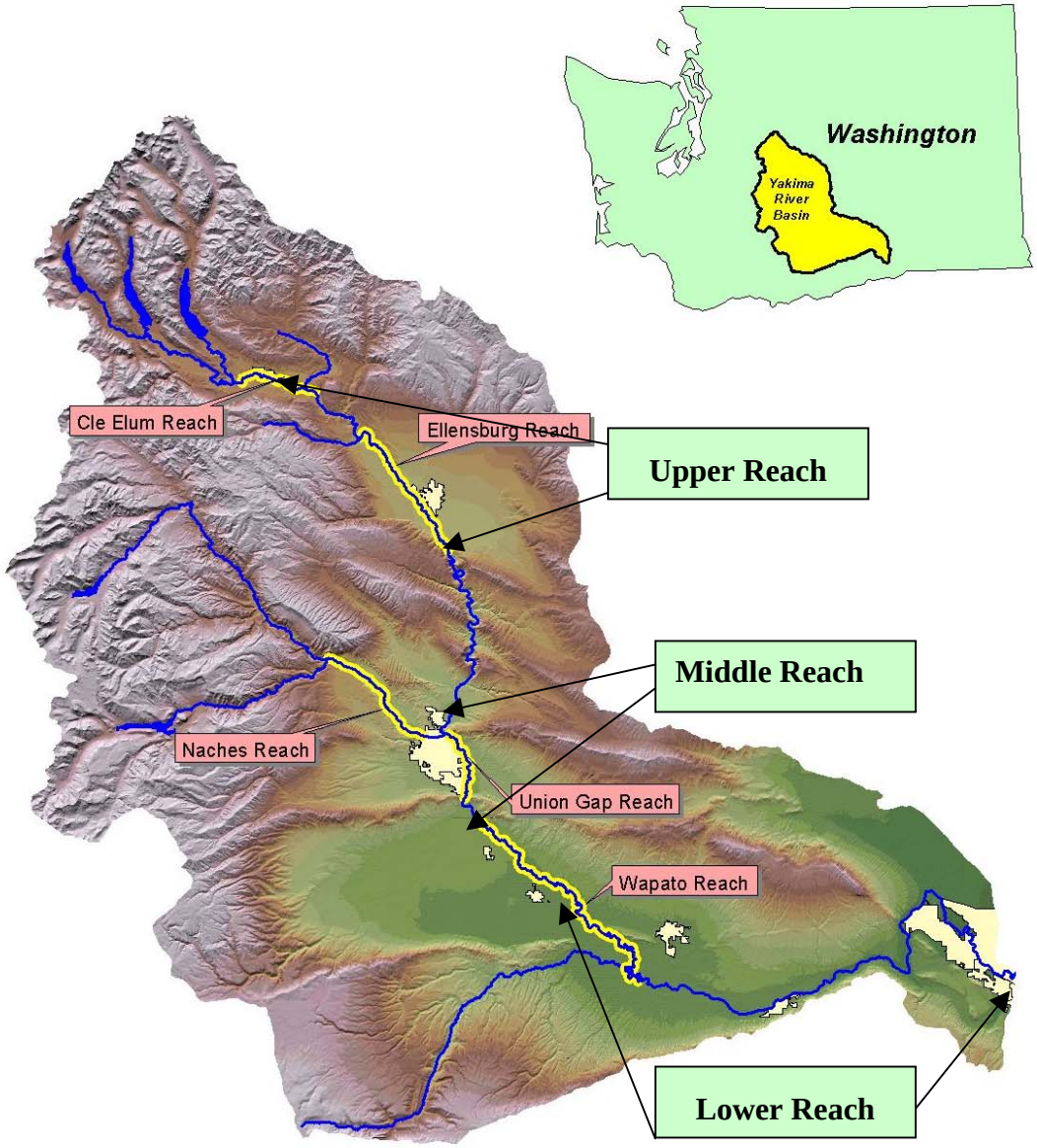

Figure 24. Thermal and ecological breaks identified between study sites in the Yakima River Basin.

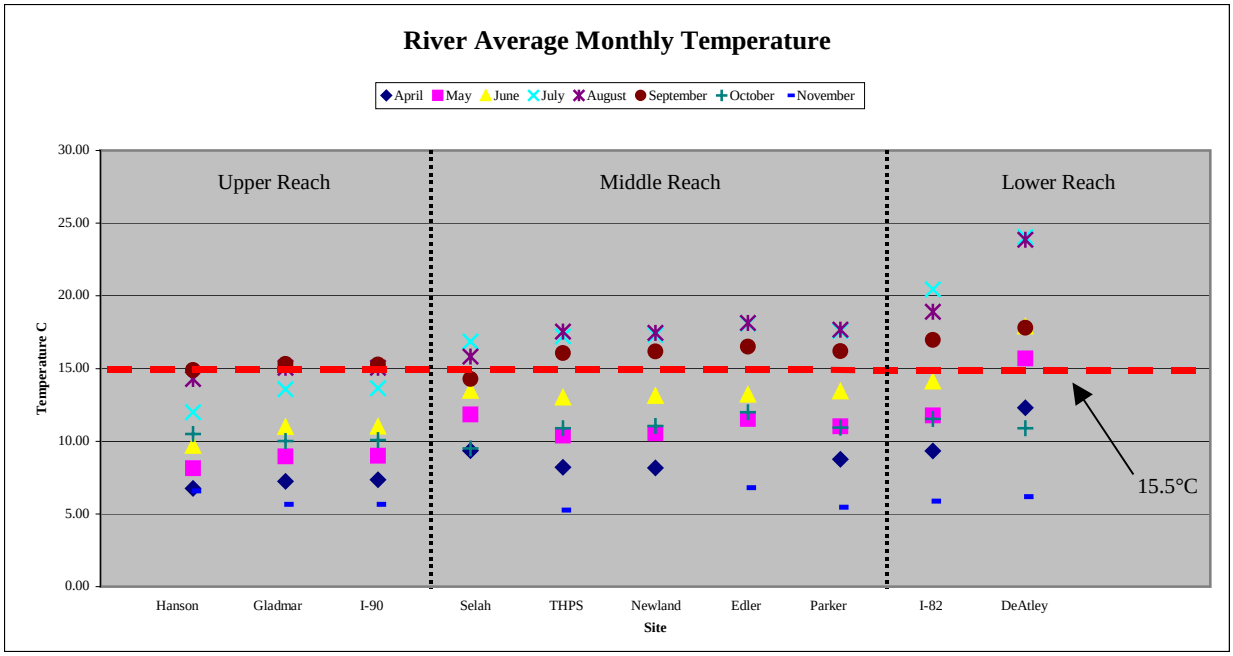

Figure 25. Average monthly temperature for the river site monitoring locations.

Upper Sites (Cle Elum to Ellensburg)

The average river temperatures at Hanson Ponds, Gladmar, and I-90 Pond 4 never exceeded an average monthly temperature of ~15.5°C, which falls just below the temperature known to impact the stress and metabolic rates anadromous salmonids. Temperatures ranging from 15.6°C-23.89°C increases stress levels and metabolic rates and temperature s >23.89°C can be fatal (Figure 25). September was the warmest month (post flip-flop) for all three of the upper basin sites, with April and May being the coolest. The range in average monthly temperatures for all three sites ranged from April to September (coolest to warmest), with June and October average monthly temperatures pairing closely with the cooler monthly average temperatures at all three sites.

Middle Sites (Selah to Parker)

The average monthly river temperature at Selah Ponds, Terrace Heights, Newland Pond, Edler Ponds, and Parker Ponds exceeded 15.6°C only during the months of July, August and September. Overall, temperatures did not exceed ~18°C, which falls within the lower temperature range that affects salmonids by increasing stress and metabolic rates. Among the middle sites, Edler Ponds experienced the highest average temperature during the months of July and August (Figure 25).

While September was the warmest month in the upper sites (due to flip-flop), August and July were the warmest months of the middle river sites. The Selah Ponds site was especially interesting, with the months of April and October pairing at the cooler end of the spectrum and the average river temperature during month of September dropping below all of the other nine sites.

Lower Sites (Parker to Richland)

The average monthly river temperature at both I-82 Ponds 4&5 and DeAtley Pond exceeds 15.6°C during the months of July, August and September, with temperatures at both sites exceeding 20°C during July (Figure 25). During the months of May and June, the average monthly river temperature exceeded 15.6°C at the DeAtley Pond site. In summary, monthly average river temperatures from April through August were dramatically higher at the DeAtley site.

Ponds

The average monthly temperature of shallowest (all at 2') and deeper comparable depths of Hanson Ponds (10'), Selah Pond 1 (12'), Newland Pond 1 (12'), and I-82 Pond 5 (14') are reflected in Figures 26 and 27. In summary, the months of June, July, and August reflected the warmest temperatures at the shallow depths (2'), exceeding 15.6°C May through September. Of the deeper monitoring locations, all four sites exceed 15°C July through September, reaching a high of ~23.93°C at Selah in August and 22.58 at I-82 Pond 5 in July. Hanson Pond exceeded 18°C May through September at the 10' depth, likely attributed to groundwater infiltration.

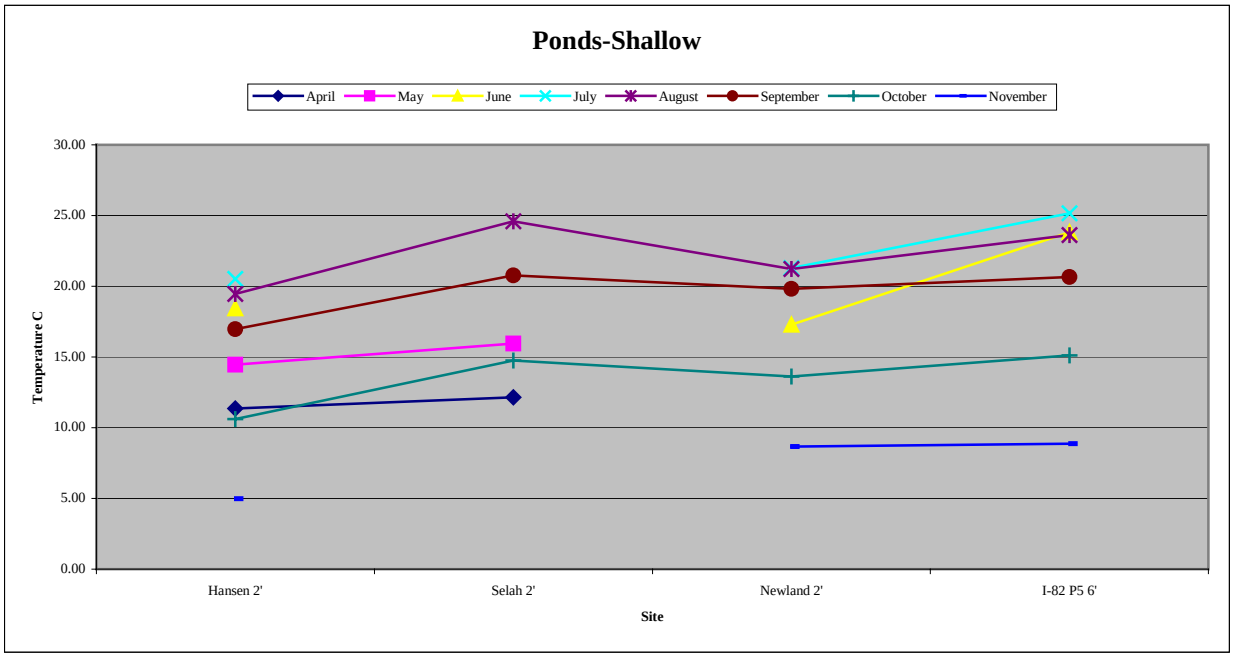

Figure 26. Average monthly temperatures at 2' depths of select ponds.

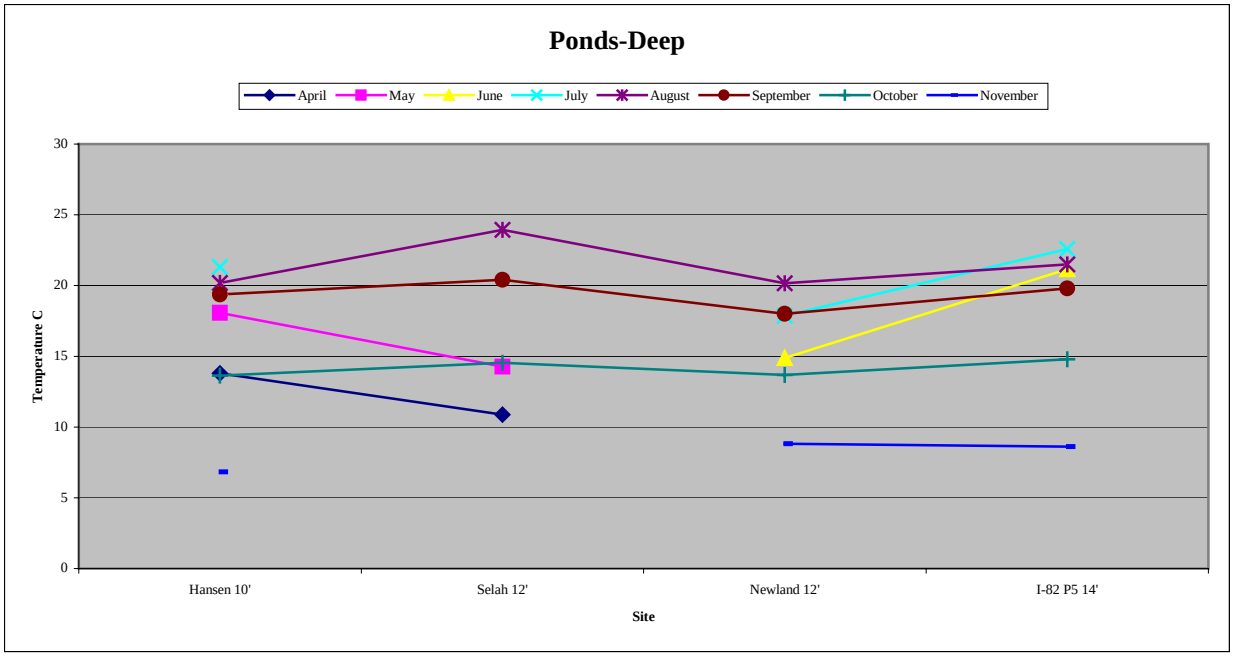

Figure 27. Average monthly temperatures at 10-14' depths of select ponds.

Thermal Discussion

The Department of Ecology is proposing to change temperature criteria for surface water bodies, including the Yakima River, through the triennial review of Chapter173-201a, Water Quality Standards for Surface Waters of the State of Washington. Ecology's proposal is to apply limits for temperature to protect key components of aquatic life such as spawning and rearing. The method of measuring whether a water body achieves the temperature criterion is based on the 7-Day Average of the Daily Maximum Temperature, or 7-DADMax. The 7 DADMax is the arithmetic average of seven consecutive measures of daily maximum temperatures, calculated using the maximum temperatures of the three days prior and the three days after that date.

The summer maximum temperature that is proposed to be protective of salmon spawning and rearing is 16°C. This temperature is applied throughout the summer to ensure that the desired spawning temperature range of 12.5^{o}C to 14°C will be met during spawning season. The summer maximum temperature that is proposed to be protective of salmon rearing is 17.5^{o}C. This temperature criterion would typically be set in the lower reaches of rivers where rearing is the only salmonid use.

The 16°C and 17.5^{o}C temperature criteria were compared to the calculated 7-DADMax data obtained at each downstream river site in this study. The sites were characterized as Upper Reach, Middle Reach, and Lower Reach following the convention in the Fish Assemblage Discussion. Graphs illustrating the monthly distribution of the 7-DADMax data compared to the temperature criteria are included in the back of Appendix I.

Table 13. Percentage of the 7-DADMax exceeding the 16°C temperature criterion.

Month	Upper Reach	Middle Reach	Lower Reach
April	0	2	8
May	0	6	50
June	0	40	48
July	23	99	100
August	63	97	100
September	78	84	98
October	12	19	16
November	0	0	0

Table 13 shows the percentage of 7-DADMax measurements that exceeded the spawning and rearing criterion of 16°C as a function of reach. The heating due to elevated summer temperatures is evident with July and August exceedences at or approaching 100% in the Middle and Lower Reaches. Leading up to the mid summer heating, the Middle Reach and the Lower Reach began to exceed the criterion as early as April while the Upper Reach remained below the criterion until July. The temperature difference among the reaches is evident in the table with the Lower Reach exceeding the temperature criterion earlier and more frequently than the Middle Reach. The Middle Reach exhibited the same character when compared to the Upper Reach.

Table 14. Percentage of the 7-DADMax that exceeds the 17.5°C temperature criterion.

Month	Upper Reach	Middle Reach	Lower Reach
April	0	0	4
May	0	0	35
June	0	17	17
July	2	82	19
August	34	78	54
September	43	63	47
October	1	10	0
November	0	0	0

Table 14 shows the percentage of 7-DADMax measurements that exceeded the rearing only criterion of 17.5°C as a function of reach. As in Table 13, the heating due to elevated summer temperatures is evident with a high percentage of exceedences during July and August in the Middle and Lower Reaches. However, the Middle Reach is indicated to have a higher percentage of exceedences than the Lower Reach. This is likely due to the lack of data at the DeAtley site during the mid summer season. Leading up to the mid summer heating, the Lower Reach began to exceed the criterion as early as April while the Middle reach was below the criterion until June and the Upper Reach remained below the criterion until July. Some of the characteristics of temperature differences among the reaches are similar to Table 13, with the Lower Reach exceeding the temperature criterion earlier than the Middle Reach. The Middle Reach became hotter earlier in the summer than the Upper Reach.